COMMISSION REPORT

PUBLIC INTEREST ENERGY RESEARCH 2013 ANNUAL REPORT

CALIFORNIA ENERGY COMMISSION

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CALIFORNIA ENERGY COMMISSION

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ABSTRACT

The California Energy Commission manages public interest energy research for electric and natural gas research programs including the Public Interest Energy Research (PIER) Program. PIER supports energy-related research, development, and demonstration for research not adequately provided by competitive and regulated markets.

This report, prepared under Public Resources Code Section 25620.8, describes PIER Electric funding and accomplishments in 2013, including activities and research projects funded from January 1, 2013 through December 31, 2013, ratepayer benefits, and program updates and initiatives.

Keywords: California Energy Commission, PIER, annual report, energy research, RD&D, energy efficiency, advanced generation, renewable energy, demand response, energy storage, buildings, distributed generation, transmission, smart grid, carbon sequestration, carbon capture, transportation, environmental, climate change, smart infrastructure, ratepayer benefits, public interest program, electricity, energy policy, loading order, jobs, clean energy, energy infrastructure, electric vehicles, greenhouse gas, Public Interest Energy Research Program, Renewables Portfolio Standard, building efficiency standards, California Public Utilities Commission

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EXECUTIVE SUMMARY

The California Energy Commission's Public Interest Energy Research (PIER) Program funds research, development, and demonstration (RD&D) projects as stipulated in Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006) to "develop, and help bring to market, energy technologies that provide increased environmental benefits, greater system reliability, and lower system costs." Research priorities are guided by California's loading order of preferred energy resources – which prioritizes Energy Commission research investment first in energy efficiency and demand response; second, in renewable energy and distributed generation; and finally, in clean fossil fuel sources and infrastructure improvements – by legislative mandates such as the Renewables Portfolio Standard (Senate Bill 1078, Sher, Chapter 516, Statutes of 2002) and the Global Warming Solutions Act of 2006 (Assembly Bill 32, Núñez, Chapter 488, Statutes of 2006), by plans such as the Energy Commission's *Integrated Energy Policy Report,* and by stakeholder input.

Investing in innovation is one of the most important pathways toward achieving California's clean energy future. Effective, policy-guided public interest energy research helps innovators and investors plan and design cost-effective solutions that will bring California into its low-carbon, diverse, efficient, and reliable energy future. Public interest energy research is an investment that yields significant benefits and lays the foundation for enormous savings into the future.

This annual report to the California Legislature, as required by Public Resources Code Section 25620.8, reports on the PIER Electric program in 2013, including specific information on award recipients, the amount of the awards, and the types of projects funded, along with an evaluation of the success of projects funded and recommendations for program improvements.

To date, the Energy Commission has invested more than $738 million for energy research and development through the PIER Electric program, leveraging its investment to attract more than $1.3 billion in match funding. Funded projects provide thousands of direct and indirect jobs to Californians, bolster California's status as a leader in energy innovation, and advance the state toward meeting its goals by helping remove barriers to a clean energy future.

Highlights of 2013 Research

The portfolio of 2013 research contained in this report demonstrates the significant advancements provided by public interest energy research efforts. Chapter 2 provides this information in full, and some of the highlights of research and benefits are summarized here.

Energy Efficiency: It is often stated that the cheapest energy is unused energy. Energy efficiency research investigates the most effective strategies and technologies to reduce electricity use and demand in the state.

Energy efficiency RD&D projects in 2013 made advancements in identifying technologies and strategies to reduce building envelope leaks. Research results show that **up to 50 percent improvement** in air tightness can be achieved, reducing the loss of conditioned air and consequently the demand for cooling and heating. Another project demonstrated high-

efficiency multimedia computers and how they could be upgraded with energy-saving components such as solid-state drives to **reduce energy use by up to 24 percent**. Data center research continued to identify new strategies for reducing energy use for cooling energy-intensive information technology systems **by up to 45 percent**.

Renewables and the Energy-Environment Nexus: In 2013, the Energy Commission funded solar forecasting and distributed renewable energy projects, enabling further incorporation of renewables in California. In addition, the Energy Commission funded development of an energy portfolio model to explore potential energy strategies and tradeoffs to achieve greenhouse gas emission reduction goals. Grid integration research demonstrated the benefits of incorporating renewable energy, energy storage, and energy efficiency into a utility grid on a military base for energy security and independence.

Energy-related environmental research in 2013 produced results and data that explored how electricity applications and products can solve environmental problems. Research on an environmentally friendly solar thermal technology could pave the way for delivering heat at a cost on par with natural gas. Another project showed that improving air quality by specifying minimum ventilation rates in commercial buildings protects people's health without unnecessary energy consumption.

Energy Infrastructure: Research into the energy systems and components that make up the electrical grid provides significant findings and benefits and identifies future research needs. The Energy Commission concluded research and demonstration improvements that led to the successful microgrid in Borrego Springs, San Diego County. The system achieved a greater than 15 percent reduction in feeder peak load and improved overall system reliability. The Borrego Springs microgrid is especially valuable in extreme outage events, providing power to affected customers until the utility grid comes back on-line.

Research successes with energy storage were advanced in 2013 with efforts to increase wider adoption of storage. Energy storage plays a major role in integrating renewables into the grid, and Energy Commission-funded research addresses technical, financial, regulatory, and market challenges that exist in increasing the role of storage in meeting California's energy goals.

Highlights of 2013 PIER Portfolio Benefits

The 2013 PIER research portfolio provides diverse benefits to California ratepayers, often resulting in a cascading effect leading to many additional benefits. Chapter 3 describes the many PIER-related benefits in full, focusing on:

- Energy savings.
- Reducing the infrastructure requirements of the electric system.
- Reducing ratepayer costs.
- Increasing the consumer appeal of innovative energy technologies.
- Addressing climate change.

- Conserving California's natural resources.
- Improving health and safety.
- Enhancing grid reliability and power quality.
- Strengthening energy security.
- Stimulating economic activity and employment.

Chapter 3 also covers in-depth benefits analyses of two past PIER projects, Winesecrets and SunPower. These projects provide extensive benefits to California, including reduced carbon dioxide greenhouse gas emissions and job creation. By 2013, Winesecrets' efficient wine purification technology saved 4 million kilowatt hours (kWh) of electricity, while SunPower's solar power installations were on track to generate 2.46 million megawatt hours (MWh) of electricity a year.

Future Research Directions

In 2011, the Legislature did not reauthorize the electricity research portion of the PIER Program and the mechanism under Public Utilities Code Section 399.8 to fund it, the Public Goods Charge (PGC). As a result, the PIER Electric program encumbered the final PIER electricity funds in June 2013, and the Energy Commission will continue to manage the remaining active projects through 2015.

In December 2011, the California Public Utilities Commission adopted the Electric Program Investment Charge (EPIC), which authorizes collecting funds from system benefits charges for renewables and research, development, and demonstration purposes. In November 2013, the CPUC approved the first triennial EPIC investment plan submitted by the Energy Commission and the three investor-owned utilities, which will fill the gaps in funding from the expiration of the PGC.

In 2014, the Energy Commission will focus public interest electricity research on:

- Developing technology improvements for a flexible and responsive electricity grid.
- Demonstrating secure, reliable microgrids and grid-linked electric vehicles to build resilient, low-carbon facilities and communities.
- Advancing grid-level energy storage innovation to achieve policy goals, lower costs, and spur investment.
- Developing a portfolio of advanced efficiency solutions, including technologies and approaches for more affordable and comfortable buildings.
- Advancing cleaner, less costly, more reliable distributed generation, power that is generated close to the location it is used, to enable customer solutions and zero-net energy communities.

- Creating a reliable and predictable renewable energy future by advancing utility-scale renewable technologies.
- Investing in the future of California's clean energy workforce.
- Building a renewable energy future that protects human and environmental health.
- Demonstrating bioenergy solutions that support California's industries, the environment, and the grid.
- Proving new efficiency and demand response technologies work for California's industrial, agricultural, and water sectors.

Under the Energy Commission, public interest has been and remains the paramount guiding theme in administering RD&D ratepayer funds. Arguments have been made, and history shows, that moving the administration to a nonpublic entity would narrow the focus to private, market-driven profits. Publicly administered RD&D ensures transparent and accountable data and research results, a balanced portfolio, maximum leveraging of funds with private and other government entities, and direct accountability to the public, ratepayers, and the Legislature. Administrators of any public interest energy research program should be held to these same goals and standards. It will also be incumbent on the administrator to coordinate the research portfolio with the California Public Utilities Commission, California Air Resources Board, utilities, and other stakeholders to avoid duplication and capture synergies.

CHAPTER 1:
Introduction and Overview

The Need for Energy Innovation

Economic vitality and social well-being depend upon affordable, safe, and reliable energy. The way society uses energy has evolved radically and has transformed the modern world, both economically and physically. Energy markets are vastly different today than they were just decades ago; use of finite fossil fuels has created not only environmental problems, but investment risks and uncertainties. For all these reasons, investing in energy innovation is absolutely critical to a bright future for California and the world.

For example, an electric system powered mainly by natural gas, oil, coal, and hydropower has little need for advanced storage technologies. But energy from renewable sources like solar and wind cannot be stored in a barrel or tank. These sources produce electricity that must either be used immediately or stored using advanced batteries, compressed air storage, hydroelectric storage, or other methods, many of which are relatively complex and new. Increasing the level of renewable energy sources will require significant technological innovation in storage technologies and large-scale deployments to balance the influx of renewable energy into California's electric grid. And this innovation must happen quickly.

Modernizing and improving energy systems preserve resources, create jobs, and can solve environmental problems. California's elected representatives have set standards to improve efficiency, reduce global warming emissions, and increase renewable energy use, among many others, with required deadlines quickly approaching. These policies, along with a growing level of private and federal investment, point toward a diverse and low-carbon energy future. But the sheer scale of the challenge means that coordination among technical, economic, and policy realities will be necessary.

For California to achieve set standards, energy innovation and infrastructure investments are necessary.

The Role of Public Interest Energy Research

While public interest energy research alone cannot provide the entire investment in innovation, the role of such research is indispensable. The California Energy Commission's Public Interest Energy Research (PIER) Program has invested in electricity research, development, and demonstration (RD&D) in energy efficiency and demand response, renewable energy resources, advanced electricity generation, transmission and distribution, energy-related transportation, and energy-related environmental research.

Public policy actors have compelling power and responsibility to invest in energy research for several reasons. Firstly, energy infrastructure decisions have a broad effect on public safety and the economy. Communities and businesses on the U.S. East Coast were left without power for weeks and in some cases for months, after "superstorm" Hurricane Sandy in October 2012. This

event was only one of many recent illustrations of the vulnerabilities of highly centralized and interconnected electric grids. In 2013, multiple articles reflected back on Hurricane Sandy, emphasizing how the storm "could prove to be a turning point in how people think about the way electricity is produced and distributed,"[1] drawing attention to the value of new tools to strengthen system resiliency and "pushing states to accelerate spending on smart grid[2] technology and distributed energy."[3] The PIER Program addresses such energy infrastructure vulnerabilities by investing directly in grid solutions that have significantly improved electricity reliability as follows: PIER-funded smart grid and microgrid projects at a California university campus, at the state's third largest jail, and in partnership with an investor-owned utility have demonstrated that these energy systems can reduce pressures on the larger electric grid and provide greater energy security in the event of outages by operating independently. Advancing these solutions will help reduce the impacts of electric system disruptions in California and provide customers with more reliable service. It will also help California meet distributed generation policy targets.

Secondly, California has unique influence on energy decisions elsewhere due to its status as one of the largest and most innovative economies in the world. California's efficiency standards and environmental policies, and the technological advancements produced by its hubs of innovation, have verified many times over the saying "As California goes, so goes the nation." Raising the bar for energy efficiency, safety, and reliability for California ratepayers often leads to the same improvements outside the state.

Figure 1: The Energy Innovation Pipeline Brings Technologies to Market

Source: California Energy Commission

But regulations are not enough, nor can public investments overcome all the barriers faced by new energy technologies. Public energy RD&D is a crucial link between researchers with an idea and investors looking for a reasonable prospect of return on their investment. The PIER

1 Magill, Bobby. 2013. "Microgrids: Hurricane Sandy Forced Cities to Rethink Power Supply." *Huffington Post*. http://www.huffingtonpost.com/2013/09/09/microgrids-hurricane-sandy_n_3895982.html.

2 The U.S. Department of Energy defines the smart grid as "a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries" (see http://energy.gov/oe/technology-development/smart-grid for more information).

3 LaMonica, Martin. 2013. "One year later, Hurricane Sandy fuels grid innovation." *GreenBiz*. http://www.greenbiz.com/blog/2013/10/24/one-year-later-hurricane-sandy-fuels-grid-innovation.

Program supports higher-risk experimental research with the potential for providing a public benefit, thus reducing private sector risk by helping demonstrate and prove the technical potential of a new idea. PIER also helps new products and practices overcome common market barriers through demonstrations, permit streamlining, incentives, goals and standards, and by making effective technologies directly available to sector customers. The Energy Innovation Pipeline demonstrates the process that brings the products of energy research to energy users and helps California achieve its energy goals.

Research improves productivity and lowers costs, fostering economic growth. Nobel laureate Robert Solow estimated that more than 90 percent of economic growth comes from investments in innovation.[4]

RD&D tends to be a higher-risk, delayed-return investment, and this can make financing and management support hard to obtain. In addition, capital markets prefer short-term return to investment, with even venture capitalists expecting to see profit in three years typically, or five years at worst.[5] Yet it is common for research benefits to peak well over a decade after the research occurred.[6] (The Energy Commission's innovation investments in integrated photovoltaic [PV] technologies, described in the "In-Depth Benefits Analyses of Technology RD&D and its Ratepayer Benefits" section of this report, exemplifies this phenomenon: The firm SunPower is producing products today based on research contracts from the last two decades.) Firms therefore invest less than would be optimal for them and collectively invest far less than would be optimal for society. In addition, private research incentives do not always align with public policy goals, and managers and investors are offered incentives to seek short-term results.

Because consumers reap the rewards of RD&D in improved products and reduced costs and because RD&D projects can inform entire industries, the social rate of return to public RD&D

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4 Cited by D. M. Kammen in testimony to Congress. 2008. "Investing in the Future: R&D Needs to Meet America's Energy and Climate Challenges."

5 Weiss, Charles; Bonvillian, William. 2009. "Structuring an Energy Technology Revolution." Massachusetts Institute of Technology.

6 Research enhances the knowledge stock creating benefits over a long period. Alston et al estimated the time stream of productivity gains from agricultural research and found the peak effect occurred around 24 years after the research.

Alston, J.M.; Andersen, M.A.; James, J.S.; Pardey, P.G. 2008. "Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending." InSTePP and Giannini Foundation Monograph. University of Minnesota, St. Paul and University of California, Davis (in preparation). Referenced in http://ageconsearch.umn.edu/bitstream/50091/2/p08-14.pdf and in http://www.landfood.unimelb.edu.au/info/seminars/2009/Alston-MelbourneUniversity-Deans%20Lecture-03-04-2009.pdf.

has been estimated at three to four times the private rate of return.[7] This is particularly relevant in the domain of energy, where failures of reliability can cost ratepayers billions of dollars, but the value of reliability is hard to incorporate in the electricity price. Meanwhile, innovation in energy efficiency faces barriers such as imperfect information and ability to process it, split landlord/tenant incentives, and the fact that individuals procuring energy for firms are not generally those making business decisions. As a result, U.S. energy firms invest only 0.2 percent of their revenues to research, far less than the 10 to 20 percent invested in the rapidly evolving information technology and pharmaceutical sectors or the 3 percent U.S. industry average.[8]

Economic studies place the optimal energy research investment at 2 to 10 times what is invested today,[9] creating a clear justification for public cofunding. Demonstration and pilot projects also are needed so that firms developing new energy technologies can work on bringing down costs, improving reliability, and creating a process for procurement and construction. However, a private firm that does such development and demonstration will find itself sharing benefits with its competitors[10] and will shy away without public help. For example, as the International Energy Agency noted, "Buildings sector companies are unlikely to fund costly, high-profile demonstrations; they feel the government should play a role in leading these exhibitions" and in creating "public outreach and education around behaviors and information management to maximize building energy efficiency."[11]

Funding RD&D that meets California ratepayers' energy needs will also help their local economies. A 1993 study of patent citations showed that "inventors that work near important sources of new ideas benefit significantly sooner from their spillovers," with six times more innovation (as measured by patent applications) in the metropolitan areas around new patents than could have been predicted by the concentration of inventors alone.[12] The Energy Commission's Energy Innovations Small Grants program has had considerable success attracting venture capital; private, nonutility, subsequent investment has exceeded the Energy Commission's investments fiftyfold. In fact, research has shown that out of all the public

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7 Nemet, Gregory F. "Policy and Innovation in Low-Carbon Energy Technologies." Ph.D. dissertation, May 2007. https://mywebspace.wisc.edu/nemet/web/Thesis.html

8 International Energy Agency (http://www.iea.org/papers/2010/global_gaps.pdf) citing National Science Board, Science and Engineering Indicators 2010.

9 Weiss and Bonvillian, *Structuring a New Energy Revolution*, cite many of these.

10 Economic and Technology Advancement Advisory Committee. 2009. "Advanced Technology to Meet California's Climate Goals: Opportunities, Barriers & Policy Solutions."

11 International Energy Agency. op cit.

12 Jaffe, Adam B. 1998. "Patents, Patent Citations, and the Dynamics of Technological Change." *National Bureau of Economic Research.* http://www.nber.org/reporter/summer98/jaffe_summer98.html., citing work the author collaborated in:
Jaffe, A.B., R. Henderson, and M. Trajtenberg. 1993. "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations." *Quarterly Journal of Economics* CVIII (3) (August): 577.

options for spending related to clean energy, private venture capitalists value their public counterparts most highly, and they recognize the value of public RD&D.[13]

California public sector leaders have a compelling power and responsibility to invest in energy research because energy infrastructure decisions have a broad effect on public safety and the economy.

Because public RD&D addresses common public needs together with innovation hurdles, helps reduce risk for private investment, and makes sure policies are reasonable and attainable, it is one of the best links between regulations passed by the state and job-stimulating, proactive investment in California.

Report Structure

The Energy Commission's *Public Interest Energy Research 2013 Annual Report* describes 2013 PIER Electric program accomplishments and benefits, new work initiated, and program updates and enhancements. Chapter 1 provides a program introduction and overview of the policies guiding the Energy Commission's public interest energy research. Chapter 2 describes major research programs and highlights selected electricity research projects and their benefits. Chapter 3 presents an overview of the benefits of PIER's 2013 research portfolio and details in-depth benefits analyses for selected projects. Chapter 4 gives a conclusion discussing PIER's legacy. Appendix A lists the electricity-funded RD&D projects that were initiated in 2013.

Policy, Planning, and Program Overview

As the state's primary energy policy and planning agency, the Energy Commission makes assessments and forecasts to develop energy policies that conserve resources, protect the environment, ensure energy reliability, enhance the state's economy, and protect public health and safety. The Energy Commission supports energy policy and planning needs and meets the provisions of Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006) by focusing research intended to:

- Support technology development to enable future building and appliance efficiency standards.
- Increase energy efficiency in major energy end-use sectors, including buildings, industrial, agricultural, and water sectors.
- Develop and integrate renewable energy into the state's electricity and natural gas systems.
- Fund needed advancements in smart grid and energy storage technology.

13 "Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international clean tech investors." *Energy Policy*, Volume 37, Issue 12, December 2009, Pages 4997–5006. http://www.sciencedirect.com/science/article/pii/S0301421509004807

- Support energy-related environmental research and transportation energy research directly tied to energy generation, transmission, and use.

Public research program administration by public agencies ensures benefits to California ratepayers by:

- Providing transparency and accountability for all funds and projects.
- Providing coordinated research to avoid duplication.
- Providing independent and impartial evaluations of proposals and projects.
- Supporting RD&D work with a statewide, policy-focused interest dedicated to benefiting California ratepayers.
- Generating research opportunities for California-based companies that create jobs and stimulate the economy.
- Building long-standing relationships with California's state universities, national laboratories, and high-tech companies that have diverse and substantial research capabilities.
- Leveraging funds with private sources and the federal government.
- Working with the Legislature to ensure the program is operating to fulfill statutory goals.

PIER and Policy: Achieving the Vision for California's Electricity Future

Policy makers have crafted a vision for California's electricity future that is vastly different from its present. Through laws, ordinances, regulations, and standards, the blueprint for this vision has emerged.

The Vision for California's Future:

California's electricity future by 2030 and beyond will be characterized by highly efficient buildings, industries, and businesses; energy generation that is low-carbon, sustainable, and distributed; and a reliable, flexible transmission and distribution infrastructure.

The following table summarizes some of California's major energy policies and standards. PIER funding decisions strive to achieve these goals and those of other policies not listed here, without sacrificing safety and reliability.

Table 1: Select Policy Goals for California's Energy Future

Policy or Standard	Goal
Governor Brown's Clean Energy Jobs Plan	California should produce 20,000 new megawatts (MW) of renewable electricity by 2020, 12,000 MW of distributed energy, and 6,500 MW from CHP.
California's Loading Order, from the California *Energy Action Plan*	Prioritizes Energy Commission research investment first in energy efficiency and demand response; second, in renewable energy and distributed generation; and finally, in clean fossil fuel sources and infrastructure improvements.
Executive Order B-18-12 – Greening State Buildings	Calls for efficiency improvements in new or renovated state buildings larger than 10,000 square feet; sets zero-net-energy (ZNE) and GHG reduction goals.
Integrated Energy Policy Report	The Energy Commission's biennial energy forecasting and assessment report (required under Senate Bill 1389 of 2002) recommends policies to foster the development of energy efficiency, renewable energy, and more.
Assembly Bill 32 (2006) - The California Global Warming Solutions Act	Requires the state to reduce greenhouse gas emissions to or below 1990 levels by 2020.
CPUC *Energy Efficiency Strategic Plan*	Sets efficiency goals, including zero-net-energy goals for new homes by 2020 and for new commercial buildings by 2030.
Senate Bill X1 2 (2011) – The Renewables Portfolio Standard	Requires all electricity retailers to meet 33% of their retail sales with renewable energy by 2020.
Senate Bill 17 (2009)	Mandates implementing and planning a smart grid.
Governor Brown's Executive Order B-16-2012 and the *2013 Zero Emission Vehicles Action Plan*	The Governor's Executive Order sets a long-term target of reaching 1.5 million zero-emission vehicles on California's roadways by 2025 and directed state agencies to "encourage the development and success of zero-emission vehicles." The *2013 Zero-Emission Vehicle Action Plan* identifies specific strategies and actions to meet this goal.
Senate Bill 1250 (2006)	Made provisions for efficiency and renewables research, declaring that it is in the best interests of the people of California that environmentally sound, safe, reliable, and affordable energy services and products be developed and that the PIER Program make research investments to this end.
The State Alternative Fuels Plan	Recommends actions to meet alternative fuel goals and sets a goal of 26% of the fuels coming from alternative sources by 2022.
Assembly Bill 2514 (2010)	Establishes an energy storage target of 1,325 MW by 2020 for investor-owned utilities.

Source: California Energy Commission

PIER Addresses Challenges Facing Policy Goals

Since its creation in 1996, the PIER Program has followed policy priorities to make funding decisions, effectively ensuring that California's energy goals are met. The diverse and ambitious goals created by California's Legislature and Governor face significant hurdles that are addressed by broad and strategic energy research.

The Breadth and Scale of the Vision: With deadlines for efficiency, renewable energy, smart grid, bioenergy, emission reduction, and many other energy goals quickly approaching, public interest energy research in all these areas helps ensure each goal can be met. Public research funding initiatives are developed openly with relevant stakeholders.

The Need for Coordination: Achieving the vision will require coordination between:

1) Efforts to improve different electricity technologies and practices that will ultimately be used together in the end-use sector, such as lighting, building envelope, and heating, ventilation, and air conditioning.

2) Innovators, investors, regulators, electricity providers, and policy decision makers to share energy research results and to ensure expectations and goals are kept realistic and efficient. Public interest energy research provides transparency that can promote coordination.

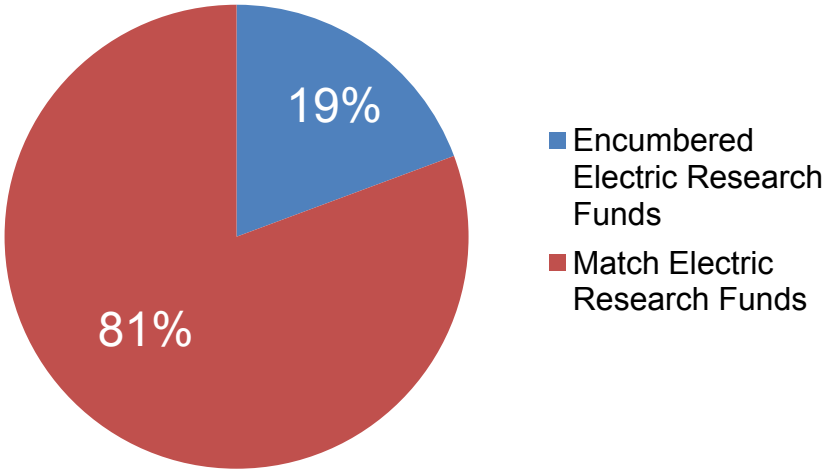
The Need for Directed Investment: Innovations often face uncertainty. Emerging technologies lack the benefit of economies of scale and often need public as well as private investment. With its record of attracting match funding many times greater than its own funding levels, PIER acts as a funnel for investment into technologies with a high potential for providing benefits and supporting public policy goals.

Making Connections to Market Success: Energy technologies and practices often must be deployed at scale within static infrastructure systems, are often part of regulated markets, and can be highly influenced by social and individual behavior. Thus, the success of a well-established and low-cost technology is often uncertain unless it is directly incorporated into existing energy standards, incentive programs, workforce training programs, or other broad pathways to market. PIER has been a successful implementer of the energy innovation pipeline to bring research results to market, which benefits innovators, electricity providers, and ratepayers.

Program Funding Overview

In 2013, the Energy Commission encumbered $23.9 million in PIER electricity funds for RD&D efforts. These funds attracted more than $102 million in match funding. Figure 2 shows the ratio of 2013 encumbered electric funds to match funds.

Figure 2: Energy Commission 2013 Encumbered Electric Research and Match Funding

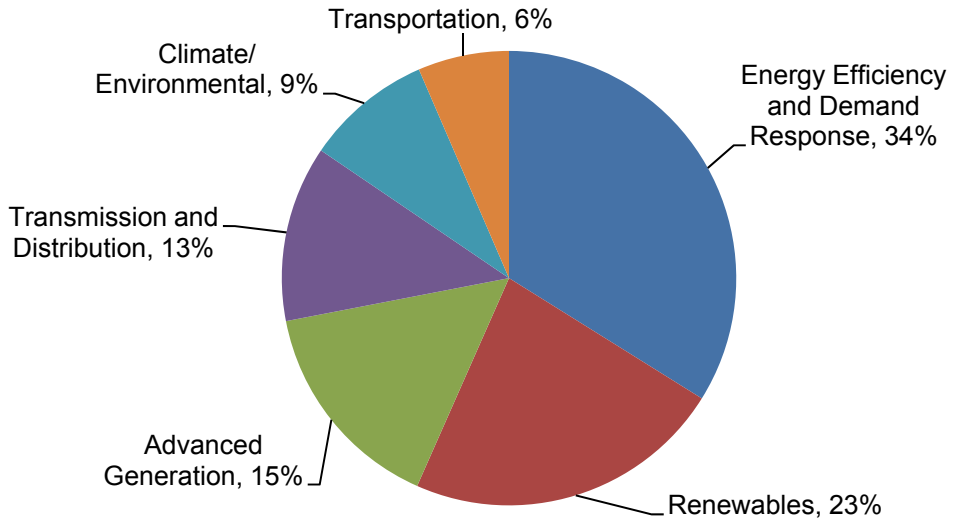


A total of $126 million in funding was initiated in 2013. This total includes $23.9 million in PIER electricity funds for RD&D efforts and $102 million in match funding. There are two main projects that contribute to this large amount of match funding: 1) Advanced Underground Compressed Air Energy Storage Demonstration Project Using a Saline Porous Rock Formation as the Storage Reservoir with PG&E received $49 million in match funding; 2) Smart Grid High Concentration Solar Photovoltaic Integration project with Burbank Water and Power received $39 million in match funding.

Source: California Energy Commission

Figure 3 illustrates how the PIER Program has prioritized projects since 1997 to align with California's loading order. By consistently funding research based on the priorities of the loading order, the Energy Commission has ensured that energy investments are made where they are most needed to achieve electric system efficiency, generation, and delivery goals.

Figure 3: Energy Commission 1997-2013 RD&D Funding Aligns With California's Energy Policies



The Energy Commission encumbered $884 million for electric and natural gas RD&D projects since 1997. More than 83 percent of the funding over the life of the PIER Program has been from electricity funds.

Source: California Energy Commission

Attracting Investment to California

To date, the Energy Commission's PIER Program has invested more than $884 million in electric and natural gas RD&D projects and leveraged these investments to attract $1.4 billion in match funding to California. More than 83 percent of this investment consisted of PIER Electric funds.

Bringing Federal Funds to California: In 2013, PIER projects continued to leverage federal funds from the American Recovery and Reinvestment Act (ARRA) of 2009. Though the vast majority of these funds were allocated before 2013, two ARRA-related projects totaling $2 million in Energy Commission funding and $88.7 million in match funding were approved by the Energy Commission in 2013. In total, Energy Commission RD&D projects have brought $639 million in ARRA-related match funds to California since 2010 at a cost of only $14.9 million of Energy Commission-administered funds. This resulted in not only an enormous investment in energy innovation at a minimal cost to California's ratepayers, but in advancements in crucial energy research areas. For example, ARRA funds supported more energy storage demonstrations in California than have ever been funded at one time in history.

Program Updates and Enhancements

Over the years, the PIER Program has matured and evolved to respond to stakeholder input. The sections that follow describe 2013 administrative activities in support of research efforts and several recent enhancements to the program. Moving forward, these practices and improvements should continue to be part of the administration of any public interest RD&D program.

Enhancing Public Outreach Strategies

The Energy Commission considerably expanded outreach and dissemination of research information to the public through various channels in 2013.

The Energy Commission held multiple research forums to share project results, promote collaboration, and seek input on the most valuable next steps, including:

- Presentation on Piezoelectric-Based Energy Harvesting Technology.
- Stakeholder Workshop on the Vehicle to Grid Roadmap.
- Staff Technical Workshops on the Development of an Energy, Air, Water, and Climate Change Co-Benefits of Renewable Power Generation and Fuels Research Roadmap.
- Transportation Research Roundup Meetings, including staff from the California Air Resources Board, California Department of Transportation, Office of Planning and Research, and the Strategic Growth Council.
- EnergyIQ Action-Oriented Benchmarking software demonstration with Lawrence Berkeley National Laboratory.
- Preapplication Workshop for the Localized Efficient and Advanced Power and Heat Systems.
- Integrated Energy Policy Report Workshop on Increasing Demand Response Capabilities in California.
- Weather Modification Working Group meeting, including members from Southern California Edison, Pacific Gas and Electric, Department of Water Resources, U.S. Bureau of Reclamation, and other water and energy agencies
- Forum for Discussion on California Energy Commission's Energy Storage Research, Development, and Demonstration Efforts and Lessons Learned

Staff also contributed to the following energy research forums, sharing results and findings with the public and stakeholders:

- United States Department of Energy's Advanced Research Projects Agency – Energy Green Electricity Network Integration Program Annual Review
- California ISO's Vehicle-Grid Integration Roadmap Workshop
- Governor's Office, Green Technology Leadership Group, ARM Holdings and the Energy Foundation's "More Than Smart: Making the Grid More Transparent, Dynamic, and Resilient" Conference
- CPUC New Residential Zero-Net-Energy Action Plan Stakeholder Meeting

- U.S.-China Clean Energy Research Center's Building Energy Efficiency Forum on Building Integrated Design, Operation, and Human Behavior
- Climate Action Team Working Group Meetings
- The Emerging Technologies Coordinating Council's meetings to discuss emerging energy efficiency research activities with staff from the investor owned utilities, Sacramento Municipal Utility District (SMUD) and the California Public Utilities Commission (CPUC)
- University of California, Irvine CalPlug Set-Top Box Workshop

The Energy Commission also organized and participated in ribbon-cutting events in 2013 that showcased thriving PIER-funded research projects. In May, the Energy Commission unveiled PG&E's Yerba Buena Battery Energy Storage System Pilot Project, an innovative battery system that better balances the power need of the electric grid to assist with intermittent renewable energy integration and increase efficiencies in matching supply with demand. In October 2013, the Energy Commission participated in a ribbon-cutting for three recently completed anaerobic digester facilities in the Sacramento region that will generate up to 5.2 MW from four facilities. In November, the Energy Commission participated in a ribbon-cutting ceremony for the Advanced Thermochemical Research Laboratory at University of California, Riverside's, College of Engineering Center for Environmental Research and Technology. The Advanced Thermochemical Research Laboratory houses an advanced gasification system known as the Steam Hydrogasification Reactor, which is 12 percent more efficient than conventional gasification technology and 35 percent more efficient than a conventional biodiesel production process.

In addition to participating in research forums and stakeholder workshops, the Energy Commission also presented its project results through project reports and informative fact sheets. In 2013, the Energy Commission published 174 final project reports and nine fact sheets on the Energy Commission website.[14]

14 All reports and fact sheets are published online at: http://www.energy.ca.gov/research/reports_pubs.html.

Figure 4: Community and Stakeholder Engagement in 2013

In 2013, the Energy Commission expanded its outreach and awareness efforts. This figure shows Commission Chair and RD&D lead Commissioner Robert B. Weisenmiller with executives and local leaders at the PG&E Battery Energy Storage System Ribbon Cutting, shared via the Commission's Facebook page.

Source: California Energy Commission

PIER Program Status

In 2011, the Legislature did not reauthorize the electricity research portion of the PIER Program and the mechanism under Public Utilities Code Section 399.8 for funding it, the Public Goods Charge (PGC). All active PIER Electric-funded projects will be managed through 2015 and the program will wind down.

New Electricity RD&D Program

Recognizing the importance and benefits of public interest energy research, Governor Jerry Brown requested in 2011 that the CPUC take action to ensure that programs like those supported by the PGC are instituted under CPUC authorities and take into account the constructive ideas for program updates that were identified during the legislative process. The CPUC adopted the Electric Program Investment Charge (EPIC) in December 2011, authorizing the collection of system benefits charges for renewables and research, development, and demonstration purposes. In November 2013, the CPUC approved the first triennial EPIC investment plan submitted by the Energy Commission and the three investor-owned utilities.[15]

As part of EPIC, the Energy Commission submits an annual report to the CPUC and the Legislature detailing program activities and highlighting funded projects. The *2013 EPIC Annual Report* provides information on the first investment plan, as well as status updates on EPIC-funded activities.

15 More information on EPIC available online at http://www.energy.ca.gov/research/epic/.

CHAPTER 2:
Public Interest Energy Research Delivers Ratepayer Benefits

In 2013, the Energy Commission funded RD&D that will address and remove barriers to achieving the state's energy policy goals. This chapter provides overviews of the research in PIER's three major areas: energy efficiency, renewable energy, and energy infrastructure. It includes a short description of each program area, followed by illustrative research highlights for projects active or completed in 2013, describing the issue addressed, project details, and benefits. Overall, the RD&D projects make up a comprehensive portfolio of promising research that will return benefits to California electricity users.

Energy Efficiency Research

California's building, industrial, agriculture, and water sectors consume more than 90 percent of the state's annual electricity, or more than 245,000 gigawatt hours (GWh) annually. As the state's population grows and the demand for energy increases, energy efficiency continues to be an important strategy for reducing energy use and cost, peak demand, greenhouse gas (GHG) emissions, and other harmful impacts associated with the inefficient use of energy. Efficiency is at the top of California's loading order, prioritizing investment in efficiency above other strategies. Since "energy efficiency is the least cost, most reliable, and most environmentally sensitive resource and minimizes our contribution to climate change," it is the resource of first choice.[16]

California has historically been successful in keeping per capita energy use low as population increased. Many modern energy efficiency challenges are related to changes in the way people use energy. Consumer electronics such as televisions, cable boxes, personal computers (including notebooks and tablets), smart phones, and other plug-in devices are quickly becoming a greater portion of overall use. Advanced technologies are powering globalization and economic opportunity, but modern data centers and other information technology support systems use a significant amount of energy. Addressing these challenges through efficiency, using both common-sense and highly advanced technologies, will allow California's innovation economy to continue to grow, unburdened by enormous energy costs and energy supply limitations.

The Golden State has long set the gold standard for efficiency as the first state to enact building and appliance efficiency requirements. PIER's efficiency research and demonstrations have helped prove the viability and cost-effectiveness of measures like "smart" lighting controls and set the stage for measures included in the state's *2013 Building Energy Efficiency Standards*.

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16 *California Energy Efficiency Strategic Plan, 2011 Update:* http://www.cpuc.ca.gov/NR/rdonlyres/A54B59C2-D571-440D-9477-3363726F573A/0/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

PIER's contribution to changes in these standards directly addresses an issue important to consumers. A 2011 Consumer Federation study about public attitudes toward energy and appliance efficiency standards concluded that nearly all Americans (95 percent) support efficiency increases, and that "the public overwhelmingly believes that improving appliance energy efficiency is beneficial and strongly supports appliance efficiency standards. Those people who are aware of minimum efficiency standards set by the government support them. They are willing to pay more for the product knowing that the additional cost will be made up over time in lower energy bills, and in fact, that they will ultimately save money."[17] The Energy Commission's efficiency research supports achievement of appliance efficiency that consumers value. The efficiency research also contributes to improved building efficiency standards and leads the path to developments in energy efficiency in the private market.

Continued energy efficiency improvements are essential to meeting the state's energy efficiency and GHG reduction goals. PIER's Energy Efficiency program area focuses on developing and demonstrating technologies, strategies, and tools that will lay a foundation for a highly efficient future.

Buildings End-Use Efficiency Research

The buildings end-use efficiency program sponsors research leading to cost-effective performance and energy efficiency improvements in new and existing buildings and their associated components and structures (such as street and parking lot lights), equipment, appliances, and consumer electronics. The program focuses on major energy-using systems, including lighting, heating, ventilating and air-conditioning (HVAC) systems, and consumer electronics, and targets:

- New and improved products.
- Energy-efficient designs, materials, building techniques, and tools.
- Improved performance and efficiency standards for buildings and equipment.

The Project: Saving Energy and Time by Sealing Leaks With Nitrogen Mist: A Novel Approach to Improving Building Efficiency

The Issue: Building envelope leaks – leaks from the external walls, windows, roof, and floor of a building – are a significant factor in energy consumption, accounting for up to 30 percent of the total energy used for HVAC systems.[18] Conventional building envelope sealing practices require many contractor hours of manually caulking and foaming leaks with no guarantee that sufficient sealing is accomplished. A promising new technology involving the use of aerosolized

17 Consumer Federation of America. 2011. *Public Attitudes Toward Energy Efficiency and Appliance Efficiency Standards: Consumers see the Benefits and Support the Standards.*

18 Sherman, M.; McWilliams, J. 2007. *Air Leakage of U.S. Homes: Model Prediction.* Lawrence Berkeley National Laboratory. http://escholarship.org/uc/item/8js1n0r3.

sealant particles to simultaneously locate, measure, and seal the leaks in a building envelope provides a comprehensive solution that can dramatically reduce total leakage.

The Research: Sealing building envelopes saves energy by reducing the loss of conditioned air and consequently the demand for cooling and heating. The Western Cooling Efficiency Center designed a compressed nitrogen system that discharges a sealant through specially designed nozzles into a pressurized room. Once released, the sealant becomes a mist of aerosolized particles that stick to wherever air is escaping, sealing the leak. The process uses commercially available blower door equipment and software that allows tracking of the sealing process and provides automatic verification that the envelope has been successfully sealed. Seven residential buildings have been tested using this technique at various stages of construction. The results show that this new sealing process can seal more than 50 percent of the remaining leaks from standard sealing practices. The next step in the research includes a full-scale demonstration at the zero-net-energy Honda Smart Home, which is under construction in West Village at the University of California at Davis. To date, about 50 percent of the leaks in the four new construction single-family homes, two new construction multifamily units, and one single-family retrofit home have been sealed using the aerosol sealing process. The Honda Smart Home demonstration also marks the first test of a new nozzle that emits smaller aerosol particles, which allows for a more consistent spray pattern and could reduce nozzle clogging.

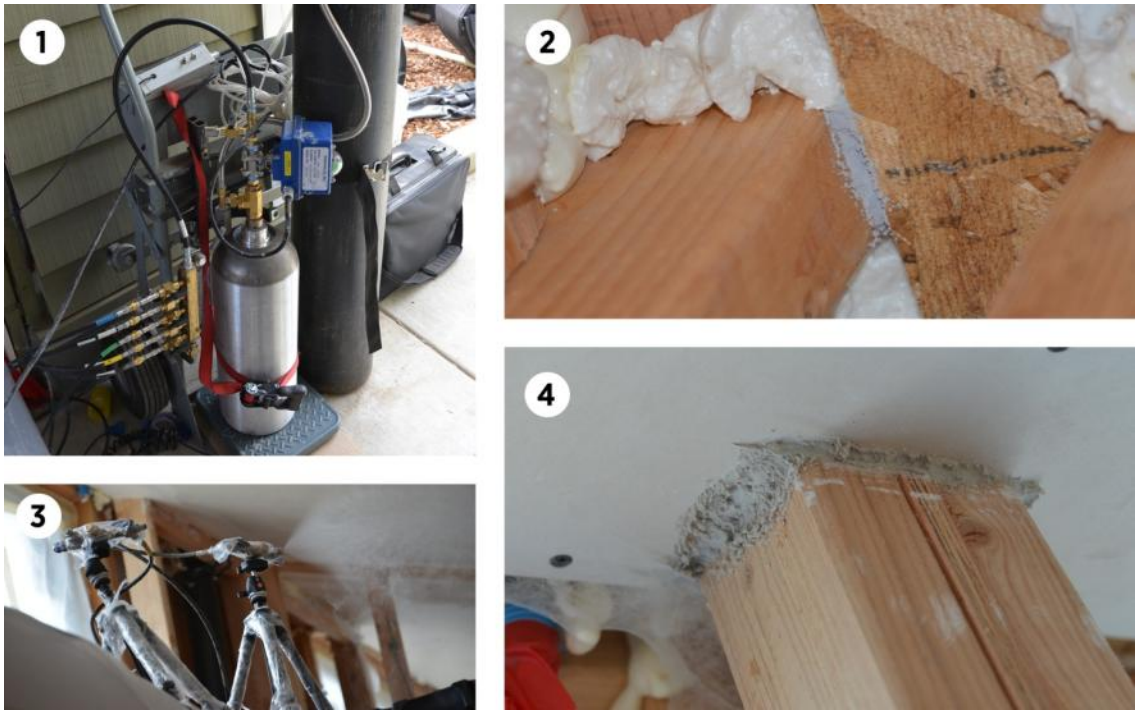
The Benefits: Sealing building envelopes with aerosol particles eliminates guess work by sealing leaks that conventional methods might miss. Preliminary results indicate that this aerosol sealing system can reduce the cost of sealing a building envelope by reducing labor and time. For example, the manual caulking process can take three contractors eight hours. Using the aerosol sealing system, on the other hand, two contractors can seal a 1,200-square-foot home in half a day, saving tens of dollars per hundred square feet and increasing overall envelope tightness. Current methods for sealing building envelopes are not adequate to cost-effectively achieve the levels of air tightness that California must strive for to meet the energy efficiency goals of the future. Preliminary research indicates that manual sealing only resulted in about 2 percent improvement in making the building tighter, but using an aerosol sealing system resulted in up to 70 percent improvement in air tightness. [19]

Automating the process of sealing leaks in buildings and homes is estimated to save up to 30 percent of the total energy used for HVAC. Current research efforts are focused on making the process more efficient by exploring alternative nozzle types and sealant compositions. The Western Cooling Efficiency Center has partnered with a large nozzle manufacturer and sealant manufacturer to test various combinations of nozzles and sealants. This testing will improve the process by reducing sealant settling issues, improving sealing rates, and improving sealant deposition efficiency at the leaks. One potential path to commercialization would be to have the system marketed by current blower door manufacturers as an accessory to their blower door

19 Fortunato, Paul. 2013. "Preliminary Results on the Honda Smart Home." Western Cooling Efficiency Center.

equipment. Current findings are presented to stakeholders at the annual affiliates' forum held at UC Davis.

Figures 5: Aerosol Injector Tools and Results



1: Aerosol injector system
2: Grey Aerosol seal after manual caulking at the Honda Smart Home in Davis, California
3: Aerosol nozzle spraying particles at the Honda Smart Home in Davis, California
4: Grey Aerosol seal on beam after manual caulking at the Honda Smart Home in Davis, California
Source: Western Cooling Efficiency Center

Agreement Number: 500-08-042 Contractor: Western Cooling Efficiency Center
Project Cost: $300,000 Cofunding: $57,000 Project Term: July 1, 2012, to June 30, 2014

The Project: Saving Energy and Improving Performance: Ultimate High Efficiency Gaming Computers

The Issue: The multimedia computing consumer gaming market is growing. According to the PC Gaming Alliance (PCGA), the gaming computer market has grown 8 percent over the past year and 90 percent over the past five years. The PCGA predicts that this market will grow from its current value of $20 billion in 2012 to about $26 billion in 2013.[20] The gaming computer market has been one of the few desktop market growth segments.

Gaming enthusiasts often build multimedia personal computers (PCs) themselves, and some computer manufacturers also provide "off the shelf," ready-built gaming systems. Performance

20 Gasior, Geoff. 2013. "PC gaming market grew 8% in 2012." *The Tech Report*. http://techreport.com/news/24575/pc-gaming-market-grew-8-in-2012.

has been the overriding criteria in choosing this type of computer, with cost and energy use not playing major roles. Some systems can consume as much energy as a refrigerator, almost 50 times the energy of a tablet computer, and more than double the energy of a conventional desktop computer. Research is needed to identify the elements of high-performance systems that can operate with lower energy use and comparable cost.

The Research: The goal of this research was to make high-performance multimedia PCs more efficient. In all, eight components on an "off-the-shelf" Hewlett Packard Pavilion© multimedia computer were replaced by components that were more energy-efficient and, in some cases, higher performance. These components resulted in the following energy savings in the retrofitted computer: solid-state drive (savings of 41.4 percent), graphic processing unit (GPU) (17.0 percent), power supply (14.3 percent), central processing unit (11.2 percent), basic input/output system (BIOS) (8.8 percent), computer case (6.2 percent), memory (1.1 percent), and motherboard.

Of the eight components modified, the greatest energy savings came from replacing the hard disk drive with an energy-efficient solid-state drive (SSD). SSDs are more energy-efficient because they use integrated circuits, having no moving parts and requiring very little power to operate. This results in significantly less heat output, which can keep the computer components cooler. When the computer runs cooler, it is also more efficient. In addition to energy savings, the SSD also increased system performance when paired with the test GPU. As prices decrease for SSDs, they will likely become a cost-effective savings measure for even standard PCs in the future. GPUs that use the new Graphics Core Next architecture – a fast and efficient high-performance computing architecture – should reduce the overall system energy consumption and allow the GPU to scale the power it demands to match the task it is completing, allowing the GPU to run cooler. A lower power 80 PLUS Gold power supply was used for the off-the-shelf computer, eliminating the need for an internal power supply fan and reducing power consumption of the system. The new CPU used a new type of trigate transistor that allows more operations per second at a much lower voltage. Memory savings occurred because the more efficient new memory operated at 1.35 volts versus 1.5 volts. The BIOS is a type of firmware (software built into the hardware) and is the initial program that boots hardware components and loads the operating system from hard drive storage. The BIOS was adjusted to allow more frequent use of low-power states. By installing a new case that allowed more natural airflow, the need for integral case fans was eliminated (See Figure 6). The new motherboard that was selected to accommodate the efficient CPU increased overall power consumption and allowed for increased performance. Had a lower performing motherboard been used, additional energy savings could have been realized.

This research demonstrated the highest potential energy savings per multimedia machine while investigating the technologies that will eventually be incorporated into mainstream computers at a lower price. These multimedia computers have increasingly fallen behind game consoles and mobile devices with regard to efficiency improvements, suggesting a large remaining potential to save energy. In addition, this work highlighted what is possible with computer

efficiency in a high-performance machine, which is a first step in developing efficiency programs and standards in electronics.

The Benefits: With the eight upgrades made to an off-the-shelf multimedia PC, total energy savings were 60.3 kWh/yr, or almost 24 percent of the baseline energy use of 255 kWh/yr. For 2013, multimedia computer sales for California are estimated at 2 million, and personal desktop computers are estimated at more than 7 million.[21] If these computers were enhanced with the upgrades identified in this research, Californians could save up to 400 million kWh annually.

Lastly, the results from this research helped provide support for the energy efficiency enhancements for desktop PCs that are now being considered under Title 20, Appliance Efficiency Standards. The results supported splitting high-performance computers into two categories based on performance capabilities. These categories included basic desktop PC and basic desktop with graphics enhancements

Figure 6: Efficient PC Case (Left) and Traditional PC Case (Right)

The Efficient PC Case (left) allows for a natural airflow to cool the computer case, resulting in overall efficiency of 6.2 percent. The Traditional PC Case (right), on the other hand, uses fans to mechanically cool the PC case.

Source: Ecova

Agreement Number: 500-10-022 Contractor: EPRI
Project Cost: $191,038[22] Cofunding: $0 Project Term: April 1, 2011, to April 1, 2014

21 Estimated assuming: 15 million gaming computers sold annually in the United States and 13 percent sales in California; 60 million PCs sold annually and 13 percent sales in California. Information calculated from the following sources: www.tomshardware.com/news/jpr-pc-gamers-numbers-pc-gaming-dead,15530.html#jpr-pc-gamers-numbers-pc-gaming-dead%2C15530.html?&_suid=138447969966903804665063344316; http://jonpeddie.com/press-releases/details/gamers-defend-desktop-and-notebook-pc-market/; PC sales based on compilation of data from Gartner (April, July 2013); and IDC Worldwide Quarterly PC Tracker (October 2013).

22 This is the total amount of the Multimedia project, one of six projects in the agreement. The total overall agreement for all six projects was $1,856,899, and total co-funding was $500,000.

The Project: Market-Ready, High-Efficiency Kiosks

The Issue: There are more than 1.2 million kiosks currently in use throughout the United States.[23] These systems exist in a range of formats and perform an array of functions, including ticketing, purchasing, ATM operations, Internet commerce, point of information, and promotions.

At the heart of each kiosk operating system is some form of computing device. Most are based on widely available desktop computers and use traditional components found in desktop computers like mechanical hard drives, desktop processors, traditional memory, and computer power supplies. Though these computers and components are relatively inexpensive and widely available, they also consume large amounts of power and may not deliver the necessary additional processing capacity. High-efficiency computing systems have the potential to dramatically reduce the overall power consumption of these devices while still providing sufficient computing, storage, and processing power to deliver kiosk functionality.

Like larger computing devices, efficient computing devices come in many forms and have a wide range of cost. Even if one assumes a higher initial cost over traditional devices, the power and operational savings from reduced power consumption over the life of the system could offset the additional costs. An average kiosk can use between 97 and 142 watts, and since these units operate 24/7, annual consumption can exceed 1,200 kWh annually per device. A high-efficiency computing device may provide sufficient savings in power costs alone to offset potential initial costs. In addition to energy savings, all kiosks tested in this project increased in performance, resulting in overall faster kiosk processing.

Figure 7: Ultra-Efficiency Computing Systems

From left to right, Ultra Efficiency Computing System Types from least to most efficient. Number 1 on the left has an annual energy savings of 0 percent over the baseline computer; Number 5 in the middle has an annual energy savings of 97 percent over the baseline computer; Number 6 on the right has an annual energy savings of 98 percent over the baseline computer.

Source: Electric Power Research Institute, Inc.

23 Summit Research Associates. 2010. *Kiosks and Interactive Technology.*

The Research: Two baseline kiosks computers were measured for power consumption and computing performance. These baseline computers performed all of the necessary functions of kiosks, and they differed in their power consumption and performance. Additionally, six high-efficiency computers or tablets were evaluated for power and computing performance. The power values and computing performances of all systems were measured, and results showed that energy savings of 84 to 98 percent can be achieved using the efficient kiosks. This information is summarized in Table 2.

The Benefits: High-efficiency computing devices offer a large amount of power savings while delivering the needed power to perform kiosk functions. Though these smaller computing devices may not be appropriate for all kiosk applications, they show potential in many applications to deliver energy savings of about 85 percent or more compared to conventional desktop computer-based kiosks. When multiplied by the large number of kiosks throughout California, these energy-saving devices could greatly reduce annual energy consumption and cost of operations of kiosks in the state.

Table 2: Annual Cost of Operations/Savings Comparison

Computing System Type	Average Power	Annual Hours of Operation	Annual Energy Savings in Percentage Over Baseline #1	Annual Energy Savings in Percentage Over Baseline
Baseline Computer #1	142.85	8760	0	0%
Baseline Computer #2	97.29	8760	399.11	32%
Ultra Efficiency #1	22.97	8760	1050.15	84%
Ultra Efficiency #2	11.5	8760	1150.63	92%
Ultra Efficiency #3	11.09	8760	1154.22	92%
Ultra Efficiency #4	8.5	8760	1176.91	94%
Ultra Efficiency #5	3.73	8760	1218.69	97%
Ultra Efficiency #6	3.13	8760	1223.95	98%

Source: Electric Power Research Institute, Inc.

Agreement Number: 500-10-022 Contractor: EPRI
Project Cost: $136,895[24] Cofunding: $0 Project Term: April 1, 2011, to April 1, 2014

24 This is the total amount of the Multimedia project, one of six projects in the agreement. The total overall agreement for all six projects was $1,856,899, and total cofunding was $500,000.

Industrial, Agriculture, and Water End-Use Efficiency Research

The industrial, agriculture, and water (IAW) sectors in California use 30 percent of all electricity consumed annually in the state.[25] These sectors are vital to California's economy and rely on an affordable, reliable, and sustained energy supply. Through RD&D, the Energy Commission seeks to improve the energy efficiency of industrial processes, agricultural operations, and water and wastewater treatment plants. These sectors are also sensitive to the reliability and quality of electric power. Therefore, in addition to improving energy efficiency, the program also researches, develops, and demonstrates technologies that help these sectors deal with power quality, supply, and reliability issues while improving energy efficiency. The major industries include food processing, cement, electronics, e-commerce, petroleum extraction, refining, and production. The sector also benefits from complementary natural gas-funded efforts to develop and demonstrate technologies that enable renewable resource-fueled processes to be substituted for natural gas-consuming processes.[26]

Examples of recent targeted technology areas include:

- Industrial energy efficiency: waste heat recovery, energy-efficient industrial heating, cooling or refrigeration, advanced sensors and controls, advanced burners, innovative combined heat and power (CHP) technologies, industrial process heating or cooling from renewable resources, and demand response.
- Water and wastewater: energy and water use optimization for water and wastewater treatment, reduction in industrial wastewater, water recycling or recovery of process wastewater, agricultural or landscape irrigation system efficiency.
- Data centers: cooling and energy use reduction and demand response, power management, innovative server designs, equipment and network improvements.
- Customer-side electricity storage: energy storage for peak-load reduction, load management or demand response, integration of renewable generation.

The Project: Reducing Data Center Cooling Costs With High-Efficiency Server Fans

The Issue: In California, data centers consume as much as 3 percent of the total energy used in the state, or roughly 9 billion kilowatt-hours per year.[27] Up to 45 percent of energy used in data

25 2011 Emerging Technology Demonstration Grant Program Solicitation, PON-11-501, revised October 2011.

26 For more information, see: Schrupp, L. 2013. Energy Research and Development Division. 2013. *Natural Gas Research and Development 2013 Annual Report.* California Energy Commission. CEC-500-2013-111.

27 Calculated from information contained in the following document and extrapolated for California: U.S. Environmental Protection Agency, ENERGY STAR Program. 2007. *Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431.*

centers is for cooling the central processing unit and other internal components of data center servers.[28] The cooling requirements become larger as data centers increase computing power and become more energy-intensive. California could require more than 4 billion kWh per year to cool data centers as the number of data centers increases and they become more critical to California's economy.

The Research: While most research efforts focus on improving efficiency of data center HVAC, hot aisle and cold aisle temperature monitoring, and other infrastructure systems, this project targeted cooling energy associated with server fans. A typical server will contain four to eight server fans, each consuming 15 watts or more, to blow cool air over hot spots in the server.

The goal of this project is to demonstrate a more effective design of server fans using the Streamlining Principle developed by PAX Scientific, Inc. The Streamlining Principle is based on biomimicry, a field of research that imitates natural concepts and applies them to manmade systems. The Streamlining Principle imitates natural flow concepts seen in air. Specifically, the Streamlining Principle exemplifies the idea that fluids in air follow a geometric path, and it incorporates this geometry into the design of the shape and angle of a fan blade in the system. The Streamlining Principle was previously applied to refrigerator and HVAC condenser fans that are now 25 to 50 percent more efficient than conventional refrigerator and condenser fans. This process was also used to develop a submersible mixer for the municipal water market that is 90 percent smaller than similar products. The success of these previous applications of the Streamlining Principle provided the basis to apply the technology to server fans.

The initial step of the research project involved establishing the baseline energy use for the "best-in-market" fans used in Cisco System servers. Next, the Streamlining Principle was used to design a fan blade for a fan that was the same size and had the same mounting characteristics as the existing fan. This was done by an iterative testing process using computer analysis and a flow chamber until the prototype fan was developed that matched the Streamlining Principle. The two fans were then compared in both stand-alone tests and tests within the servers at Cisco Systems in San Jose. The PAX fans achieved a 35 to 45 percent power reduction over the existing fans, surpassing the project's 15 percent power reduction goal. With the success of the PAX fans in the first class of servers, the same process was repeated with a second class of servers that required a higher output fan. The PAX fans for this class of server achieved a 20 to 25 percent power reduction over the existing fans.

The Benefits: PAX's data server fans reduce the amount of turbulence in the air before and after contact with the fan blades. Because of the unique design of the blades, these fans are proving to be quieter and use less energy for the same electric output as conventional fans while improving performance. It is estimated that California data centers have roughly 300,000 2U

28 U.S. Environmental Protection Agency, ENERGY STAR Program. 2007. *Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431*. www.energystar.gov/ia/partners/prod_development/downloads/EPA_Datacenter_Report_Congress_Final1.pdf?8677-5fe8

size servers,[29] consuming 158 million kilowatt hours per year just on fan power alone.[30] If the PAX fans replace all the server fans in these servers, achieving a 20 to 45 percent power reduction, the estimated power and peak electric demand savings of these servers would be 32 million kilowatt hours per year.

Figure 8: Prototype PAX Fan, Undergoing Testing

Source: PAX Scientific

Agreement Number: PIR-10-020 Contractor: PAX Scientific
Project Cost: $287,757 Co-funding: $96,188 Project Term: March 1, 2011, to September 1, 2014

Energy Generation Research

Renewable Energy Research

One of the building blocks that will be required to construct California's energy future is the increased use of renewable sources of energy. Multiple state-level policies require California to bolster its renewable energy portfolio. For these reasons, the Energy Research and Development Division's Renewable Energy Program research targets key technological, performance, and

29 A rack unit, U or RU, is a unit of measure that describes the height of equipment designed to mount in a 19-inch rack or a 23-inch rack. One rack unit is 1.75 inches high (taken from http://en.wikipedia.org/wiki/Rack_unit).

30 U.S. Environmental Protection Agency, Energy Star Program. 2007. *Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431*. www.energystar.gov/ia/partners/prod_development/downloads/EPA_Datacenter_Report_Congress_Final1.pdf?8677-5fe8.

integration barriers of renewable resources such as biomass, solar, wind, and geothermal energy.

The Project: Forecasting Technologies to Boost Solar Energy Production in the Golden State

The Issue: One of the critical challenges to greater penetration of solar photovoltaic (PV) renewable energy into the state's electricity system is the variability of energy production associated with solar PV plants. Such challenges could create serious concerns on California's grid planning and electricity operating system to maintain a sustainable electricity supply.

The Research: Clean Power Research® developed a unique method to predict power production from a given PV fleet. This method, FleetView™, uses inputs of satellite-derived solar resource data and the design attributes and locations of PV systems. It combines these inputs with advanced algorithms to track cloud patterns to predict output. The PV fleet power production variability modeling results suggest that 3 percent relative mean absolute error can be achieved for PV fleet simulation for 15-minute interval data over a six-week period given that accurate location-specific solar resource data are supplied; correct PV specifications are used; the PV simulation model is properly tuned; and PV plant operating status is reflected in the simulation to account for poor performance. Results also suggest that the total error is as low as 3 percent but can increase to more than 7 percent if the model is not tuned and PV plant operating status is not reflected in the simulation. The simulated results were compared with measured PV power production data (provided by the California Independent System Operator) to identify performance issues.

The Benefits: As a result of this effort, Clean Power Research is now producing seven day-ahead forecasts every half hour for more than 170,000 PV systems within the California Independent System Operator's (California ISO's) balancing area. Access to this information provides the following benefits:

- Prediction of behind-the-meter PV fleet performance for the first time.
- Fleet forecasts categorized by California ISO's five regions for both behind-the-meter and metered PV.
- Greater level of confidence in Clean Power Research's PV fleet simulation accuracy.
- Better understanding of the performance of metered PV plants.
- Better positioned to begin evaluating integration of PV fleet forecasts into load forecasts.
- Availability of prediction tools to support PV fleet forecasting and to produce key data necessary for the future planning of PV integration into the grid.

The California ISO also sees potential of using the approach directly or indirectly to calibrate its studies of system operations under alternative renewable energy scenarios.

Additionally, the U.S. Department of Energy recently awarded Clean Power Research about $1.5 million to help advance the commercialization of FleetView™ software, which will provide benefits to ratepayers by potentially helping reduce the costs of solar and integrating distributed PV fleet forecasts into grid operations.

Figure 9: California ISO PV Fleet System Mapping Process

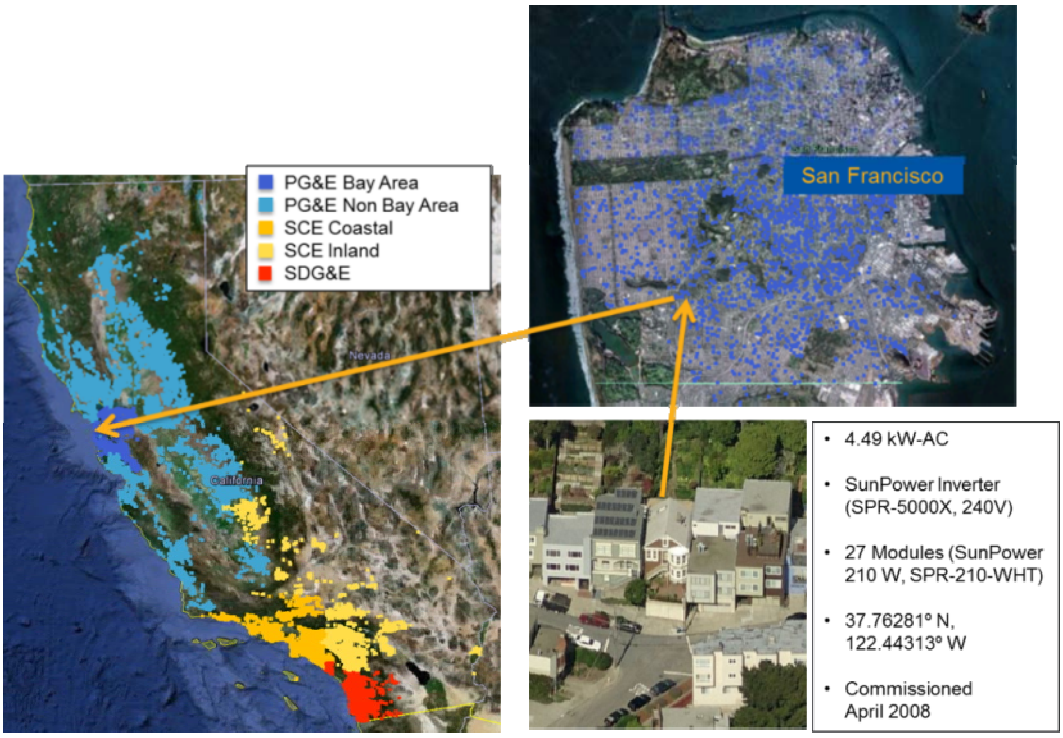


Figure 10 illustrates the mapping process for one PV system. Detailed PV specification data for a single system (lower right) was mapped to the city of San Francisco (upper right). This, in turn, was mapped to the PG&E Bay Area California ISO region (left). The process and simulations result in more accurate power production predictions over a wider geographic area.

Source: Clean Power Research

Agreement Number: 500-10-059 Contractor: Clean Power Research
Project Cost: $450,000 Co-funding: $90,000 Project Term: June 30, 2011, to June 30, 2013

Energy Storage: A Necessary Link Between Renewables and a Modern Electricity System

California's power grid delivers electricity to millions of people continuously as it is generated. However, energy from renewable sources like solar and wind is intermittent and can be unpredictable with varying generation that does not always align with demand. Energy storage fills the gap between when renewable electricity is generated and when it must be used. It also can help grid operators and utilities take full advantage of abundant renewable energy while providing reliable electricity, matching supply with changing demand.

In California's low-carbon, flexible-grid future, energy storage will be used for multiple purposes. Energy storage technologies can help store energy in periods of low demand and

high production, and they can regulate the output power of renewable generation sources so they are more easily integrated into the overall grid. Using energy storage to smooth renewable output also prevents GHG emissions from conventional fossil fuel generators that have predominantly been used for this purpose because storage and battery technologies were not advanced enough.

As California advances toward its Renewables Portfolio Standard (RPS) goals, the role of energy storage in successfully integrating renewables into the grid is becoming significant. In 2010, California Assembly Bill 2514 (Skinner, Statutes of 2010) was signed into law, recognizing the importance of energy storage in meeting the goals in the RPS and Assembly Bill 32. In 2013, the CPUC established an energy storage procurement target of 1,325 MW by 2020 for three investor-owned utilities in California.

The Energy Commission supports research, development, and demonstrations of various energy storage technologies and products. To date, the Energy Commission has funded 20 energy storage research projects, all at different stages of completion, including RD&D of batteries (zinc-halogen, sodium-sulfur, iron-chromium, and lithium-ion), flywheels, and compressed air energy storage for bulk energy storage. Each of these energy storage projects is working to overcome common challenges in areas such as cost, operation, permitting, durability, performance validation, safety, and reliability.

These energy storage projects provide experience and lessons learned that will help California achieve its policy goals, enabling energy storage to help stabilize the grid and increase overall system reliability.

The Project: Integrating Battery Storage for Distributed Renewable Energy in Energy-Efficient Residential Communities

The Issue: Distributed solar photovoltaics in rooftop and ground-mounted applications represent the greatest opportunity for implementing distributed renewable energy in California over the next 10 years. However, a number of technical issues limit the amount of PV that can be integrated into the grid at the distribution level. Such problems include grid communication challenges, insufficient testing of distributed PV in a high-penetration scenario, inadequate models and forecasting techniques to consider distributed PV as a grid resource, and lack of data on the potential of using energy storage to address the variable output of PV. These issues need to be addressed to fully understand both the feasibility of deploying distributed PV on a larger scale and the roles that batteries can play to promote wider PV deployment.

The Research: This American Recovery and Reinvestment Act cofunded project is evaluating the potential uses and benefits of lithium-ion battery storage applications in the energy-efficient Anatolia community located in Rancho Cordova in Sacramento County. This high-penetration solar community has advanced metering and communication infrastructure where there is an average of 2 kilowatts of PV installed per house.

This project is assessing the potential use and benefits of battery storage coupled with high-penetration PV in three configurations: community energy storage, which is located near the transformer and provides storage for a number of homes; residential energy storage, which is located in an individual residence and provides storage for only one home; and lastly, a control group of homes configured with no storage to serve as a baseline. Advanced metering and communication infrastructure are installed in the Anatolia community, allowing SMUD to monitor and control the energy storage systems, PV system output, and customer loads. Consumers were also able to monitor their energy usage, PV output, and energy storage in real time. A variety of potential use cases are being evaluated, including firming of renewable PV resources to smooth intermittency, reducing demand at high-priced critical peak periods, and distributing voltage support for the local electricity infrastructure.

Some preliminary lessons learned from this demonstration include consideration of the technical complexity and schedule flexibility needed to test, certify, and integrate various component technologies, coordinate and resolve technical and contracting issues with numerous technology vendors, and acquire and analyze the appropriate data to yield useful results. Perhaps counterintuitively, customers preferred to have energy storage systems installed in their garages rather than having one of the larger batteries installed on the front lawn near sites of existing transformers. The batteries installed in customer garages, however, created additional complexities for SMUD when it came to gaining access for service and maintenance. SMUD indicated that for future distributed energy storage, it would be more convenient to have systems sited outside customer homes, similar to electricity meters, so they would be easier to access.

The Benefits: This project will provide SMUD and other California utilities valuable lessons for future high-penetration solar community projects, which will help build a strategy for integrating energy storage and PV that can be replicated throughout the utility industry. The assessment of potential use cases and benefits of using distributed energy storage to serve a wide range of functions will allow for future projects to effectively target investments to those functions that provide the largest benefit to utilities and ratepayers.

The potential benefits of energy storage assets vary by the specific function that those assets provide, and they can broadly be categorized into environmental, reliability, and economic benefits. Environmental benefits include reductions in criteria pollutants and carbon dioxide emissions; reliability benefits include reduction in outage frequency and increased power quality; economic benefits include improved asset use and avoided transmission and distribution capital costs.

Figure 10: Resident Energy Systems Installed in Customer Garages

Source: SMUD

Agreement Number: PIR-10-004 Contractor: Sacramento Municipal Utility District
Project Cost: $500,000 ARRA Cofunding: $6,016,174 Project Term: June 30, 2011, to March 31, 2015

The Project: Improving Grid Reliability With Intelligent Microgrids at Camp Pendleton

The Issue: Integrating the increasing number and variety of renewables into the state's electrical system is becoming more important every day. Incorporating higher levels of renewables and other innovative technologies raises the challenge of efficiently operating the grid while producing affordable, stable, predictable, and reliable power on a large scale. Such factors create the need for power supply optimization and energy management.

Microgrids are becoming widely used by military installations, communities, and campuses across the nation to address these challenges, increasing independence from grid instabilities and incorporating cleaner power into the grid, offering greater energy security and reliability.

The Research: The FractalGrid Demonstration Project demonstrates interconnected, cyber-secure, and intelligent microgrids that use a system approach to integrate community-scale renewable energy, energy storage, energy efficiency, and other technologies within an existing utility grid at Camp Pendleton. Camp Pendleton is a large marine base in San Diego County with dispersed electric loads and generation. There is local renewable energy generation, including on-site flat-plate and concentrating photovoltaics, and the project includes installation of advanced power controllers, distribution and isolation switches, and localized energy storage. These additions will optimize energy demand by making it more reliable and secure. The technologies demonstrated have potential applications for high-risk clients, such as large industrial institutions and army bases.

This research shows the capabilities of and interactions between microgrids. For example, in an outage, these innovative technologies enable the operator to shed electric loads to support vital base functions, thus providing long-term energy security to the facility. The fractal microgrid

approach also shows the interoperability of power systems, proving the infinite scalability because of the identical nature of the components and subcomponents of these power systems. Lastly, the microgrids communicate with each other and the local utility grid at all levels to react to near real-time events and changing environmental conditions**.** This project is a milestone in how renewable-based communities and microgrids can interact with one another in California. If successful, the FractalGrid Demonstration Project will help achieve numerous U.S. Department of Defense renewable energy and energy security goals, as well as California's ambitious energy goals.

Figure 11: Camp Pendleton Microgrid Schematic

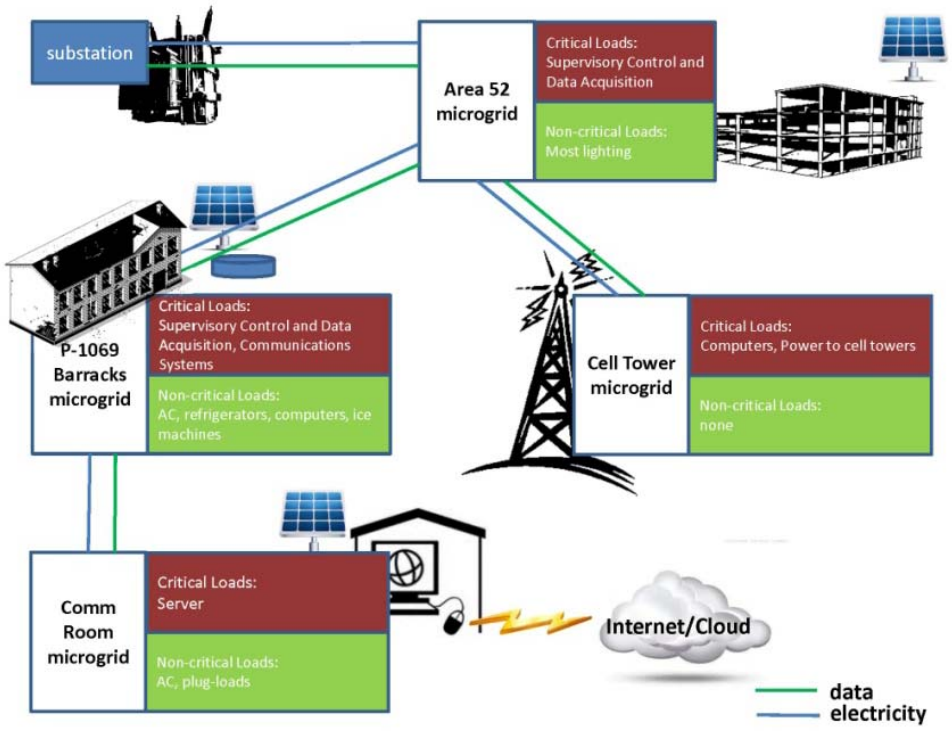


Figure 11 shows the Camp Pendleton FractalGrid System Architecture Design, including critical loads for the different elements of the microgrid.

Source: Art Villanueva (Harper Construction Company) for the Camp Pendleton FractalGrid Systems Architecture Design

The Benefits: The FractalGrid architecture allows islanding, or separation, of multiple distributed microgrids both from the local utility grid as well as from other microgrids. Additionally, the Camp Pendleton microgrid will reduce the community's daily energy consumption by 10 percent by optimizing generation and load resources; reduce peak demand kilowatts by 10 percent using energy storage; and reduce carbon footprint by at least 5 percent against the baseline using solar forecasting.

Figure 12: Camp Pendleton Locally Available, On-Site, Flat-Plate, and Concentrating Photovoltaics

Source: Harper Construction Company and Specialized Energy Solutions Design Report

Agreement Number: PIR-12-033 Contractor: Harper Construction Company, Inc.
Project Cost: $1,722,890 Co-funding: $1,172,428 Project Term: June 30, 2013, to March 31, 2015

Energy-Related Environmental Research

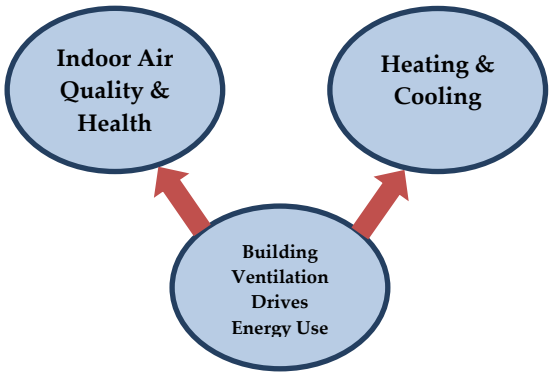
The energy sector has broad implications for the environment, and while California builds its renewable energy portfolio to attain its envisioned energy future, it must also support its legacy of visionary environmental policy goals. The Research and Development Division's Energy-Related Environmental Program develops cost-effective approaches to evaluating and resolving environmental effects of energy production, delivery, and use in California. Even further, it explores how new energy applications and products can solve environmental problems. This energy-environment nexus research fills the critical need of informing decision makers and stakeholders on the environmental implications of developing technology by improving regulatory decision-making and informing policy.

The Project: Improving Air Quality in Commercial Buildings Without Wasting Energy

The Issue: California's Title 24 Standards specify minimum outdoor air ventilation rates (VRs) for commercial buildings that are intended to strike a balance between the energy costs and indoor air quality benefits of ventilation. However, the minimum VRs in Title 24 and in other codes and standards are largely based on decades-old research that considered only the amount

of ventilation needed to maintain acceptable perceived air quality based on the occupants. This research did not consider how VRs affect peoples' health. Also, the amount of ventilation needed to remove pollutants emitted from building materials, furnishings, and equipment was not considered. Therefore, large gaps in knowledge about the effects of minimum VRs on health, work performance, and building energy consumption exist, and they have been a barrier to the development of scientifically based ventilation standards.

Figure 13: Linkages of Building Ventilation, Energy Use, and Occupants' Health and Performance



Building ventilation, energy use, and occupants' health and performance are all linked. Not only does building ventilation drive energy use through fan use and conditioning air for heating and cooling, but it affects overall indoor air quality and heath for building occupants.

Source: Lawrence Berkeley National Laboratory

The Research: The goal of this multitask project is to develop information that will enable future versions of Title 24 standards to specify minimum VRs for commercial buildings that protect peoples' health without wasting energy. Project tasks, some completed and some ongoing, include:

- Quantifying how minimum VRs in California's commercial buildings affect energy use as a function of climate.
- Evaluating the potential to simultaneously save energy and improve average indoor air quality through monthly or seasonal adjustment of minimum VRs.
- Determining how VRs affect indoor air pollutant concentrations.
- Identifying for offices, schools, and stores the key indoor air pollutants that pose significant risks of chronic health effects that vary with VR, and quantifying the associated health risks.
- Determining how VRs in offices affect "sick building syndrome" symptoms, satisfaction with air quality, cases of respiratory infections, and days of illness-caused absences. "Sick building syndrome" is used to describe situations in which building occupants

experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified.[31]

- Surveying VRs and pollutant levels in retail buildings and enabling an evaluation of chronic health risks at different VRs.
- Assessing how VR per occupant and VR per floor area in a simulated office independently affect "sick building syndrome" symptoms and cognitive performance.
- Evaluating the benefits of and problems with the American Society of Heating, Refrigerating and Air-Conditioning Engineers' optional performance-based procedure for setting minimum VRs, and providing recommendations with respect to adoption of a similar procedure in California's Title 24 Standards.
- Developing a systematic procedure for using the results of research from this project and elsewhere to select minimum VRs for commercial buildings.

The Benefits: Preliminary results provided compelling evidence that outdoor air ventilation influences human performance even when perceived air quality issues are not detected or "sick building syndrome" symptoms are not present. In addition, estimated formaldehyde emission rates suggested that retail stores would need to ventilate at levels far exceeding the current Title 24 requirement to lower indoor concentrations below California's stringent formaldehyde reference level. Lastly, the project researched many pollutants comprising criteria pollutants, volatile organic compounds, semivolatile organic compounds, and biological contaminants that are found in commercial buildings. Focusing primarily on identifying potential volatile organic containments of concern, the project identified about 30 that are impacted by ventilation.

This research provides critical information and developing procedures that enable California to specify minimum VRs for commercial buildings. These VRs strike a balance between energy costs and people's health, satisfaction with air quality, and work performance. In addition, building operators will be able to use these results to make informed choices of the VRs provided in their buildings, and California residents will benefit from the creation of health-protective conditions in buildings without unnecessary energy consumption.

31 EPA, *Indoor Air Facts No. 4 Sick Building Syndrome.* 1991. http://www.epa.gov/iaq/pdfs/sick_building_factsheet.pdf.

Figure 14: Building Testing in California

Building testing for this project is taking place throughout California, with 7 buildings total being tested in the Central Valley (green), 19 total in the Bay Area (blue), and 11 total on the South Coast (yellow).

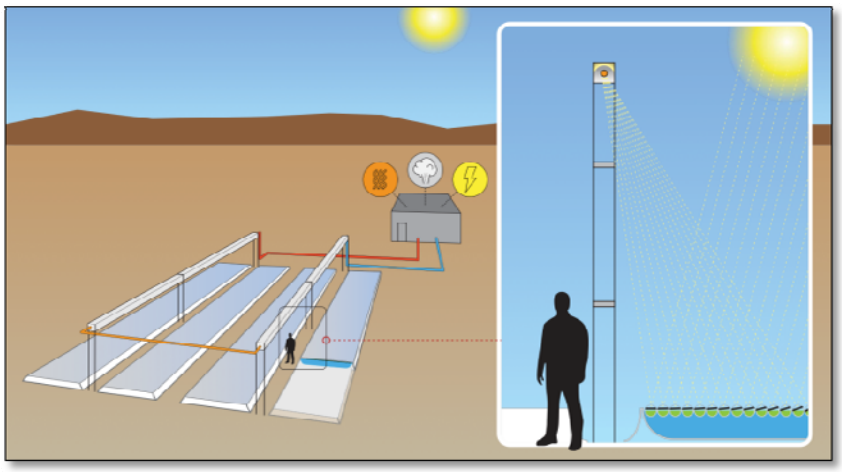
Source: California Energy Commission

Agreement Number: 500-09-049 Contractor: Lawrence Berkeley National Laboratory
Project Cost: $3,400,000 Co-funding: $0 Project Term: August 13, 2010, to March 15, 2015

The Project: Demonstrating Low-Cost Solar Energy Technologies That Conserve Natural Resources

The Issue: Solar energy is playing an important role in helping California achieve its Renewables Portfolio Standard goals. Utility-scale solar development, however, requires an immense amount of land and can have negative impacts on delicate ecosystems and vulnerable species, particularly in the desert. The environmental footprint of these solar technologies may prove a barrier to greater penetration of this renewable energy source. Thus, there is a need for innovative solar technologies with reduced land requirements. One example of this technology is the linear Fresnel reflector technology, which uses long, thin segments of mirrors to focus sunlight onto a fixed collector located at a common focal point of the reflectors. These systems are less costly and more land-efficient than other solar technologies and they are scalable in size.

Figure 15: Hyperlight® Technology Perspective View, and Cross Section



Typical layout and the scale of a Hyperlight® system providing steam for power generation or other process needing steam.

Source: Combined Power LLC

The Research: The Hyperlight® Ultra Low-Cost Solar Thermal Technology provides the benefits of the linear Fresnel reflector technology at a potentially much lower cost. This project seeks to reduce the cost of linear Fresnel by developing a feasible, low-cost effective solution to holding reflectors in place and tracking the sun. Hyperlight® mounts the solar reflectors on long, small-diameter plastic tubes that float in water. The large surface areas of these tubes can be controlled with minimal structural support and control hardware, and using water as a foundation ensures that the tubes float on a perfectly flat surface.

A pilot project with 25-meter-long tubes and 27 percent efficiency was demonstrated at Santee, San Diego County, and going forward, a scaled-up system with a higher efficiency receiver will be installed and field tested in Brawley, Imperial County.

The Benefits: Hyperlight® technology has even lower land requirements than conventional linear Fresnel technology because it can space the reflectors closer together, allowing for greater usage of disturbed and developed lands to expand site selection options. Even more, the technology is lower cost because it uses lower-cost materials. Because of this, smaller projects can be built on small parcels of land, thus increasing opportunities to avoid undisturbed habitats and large areas of remote and environmentally sensitive areas, including deserts.

Preliminary results suggest that Hyperlight® will be cost-competitive with natural gas in some markets. Based on the expected cost to produce the Hyperlight® product, the system is on track to achieve a price of $5 per 1million British thermal units for delivered heat in 2017 without any state subsidies or incentives. This cost for heat is on par with natural gas and, if achieved, would pave the way for 6¢ to 10¢ per kilowatt hour for electricity generated with Hyperlight® technology. Such cost projections illustrate the transformative effect this type of technology could have on the solar energy market, saving ratepayers money and moving California closer to its renewable energy goals.

Figure 16: Hyperlight® Demonstration in Santee, California

Pilot project demonstration site in Santee with 25-meter-long tubes floating in water basins and fixed collector between the basins.

Source: Combined Power LLC

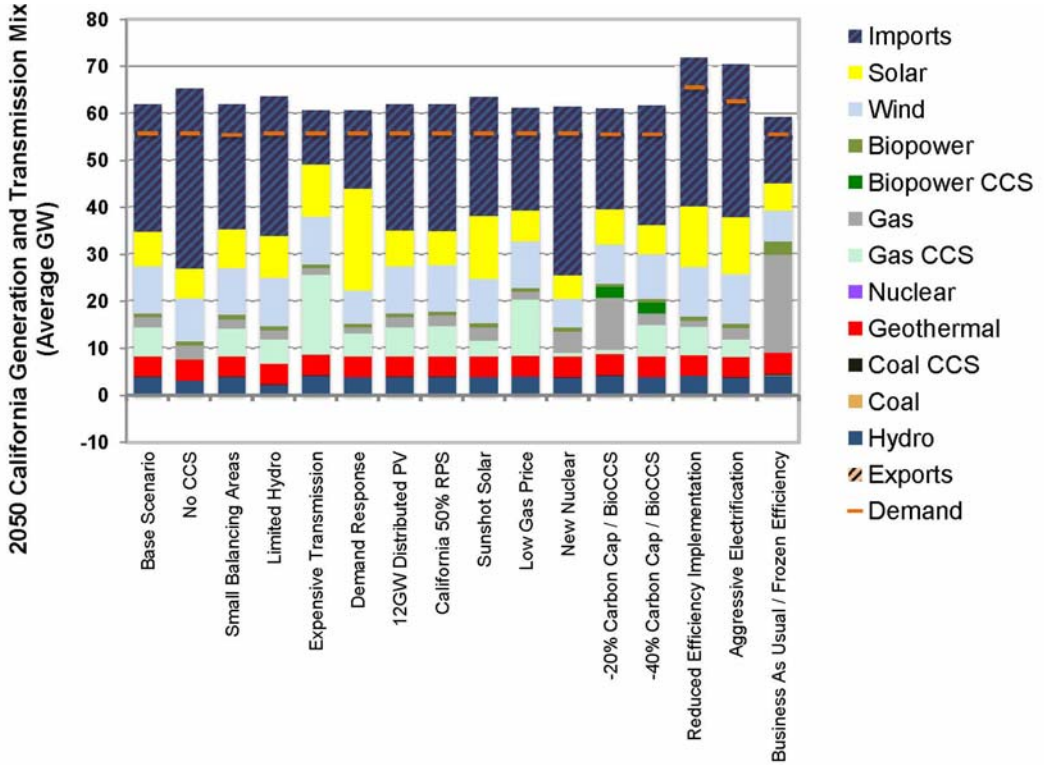
Agreement Number: 500-10-603 Contractor: Combined Power LLC
Project Cost: $1,000,000 Co-funding: $514,965 Project Term: June 30, 2011, to March 30, 2015

The Project: Potential Scenarios for California's Energy Future

The Issue: The California energy system must change drastically over the next few decades in response to mandates to reduce greenhouse gas emissions and substantially increase the contribution of renewables to the electricity mix. Switching fuel from oil and natural gas to renewable electricity is a key strategy in meeting these goals. There are four key elements critical to achieving the state's 2050 target to reduce GHG emissions by 80 percent from the 1990 level: 1) aggressive energy efficiency programs; 2) zero or near-zero carbon electricity; 3) widespread electrification of passenger vehicles, building heating, and industry heating; and 4) large-scale production of low-carbon-footprint biofuels to replace largely petroleum-based liquid fuels for transportation services that cannot be electrified (for example, air transport).

The Research: This project used a suite of models to explore how the energy system must evolve over the next few decades to meet California's energy and climate goals. It employed SWITCH, a state-of-the-art planning model for the electric power system, to investigate the evolution of the western North American power system from present day to 2050 in the context of deep decarbonization of the electricity system. In addition, the research team used models to simulate the rest of the energy system, including energy demand for transportation, buildings, and industry. This integrated modeling system analyzed long-term energy system scenarios for California consistent with the state meeting its 2050 climate targets, including detailed analysis and assessment of electricity system buildout, operation, and costs across the Western Electricity Coordinating Council region.

Figure 17: California's Average Generation Mix by Fuel, Imports and Exports, and Demand in 2050 for All Scenarios Considered



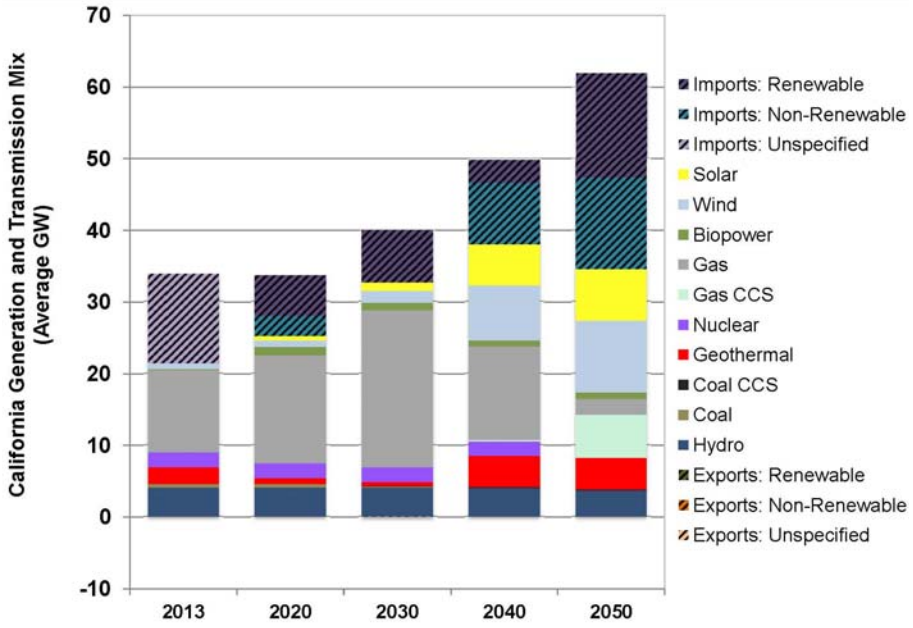
Source: Nelson, J et. al. 2013. *California's Carbon Challenge Phase II Final Report.*

Results indicated that drastic carbon emission reductions in the power system are feasible by 2050 under a wide range of scenarios (Figure 17). However, policy choices greatly affect compliance costs. For example, the Department of Energy's SunShot initiative, which will reduce the total costs of PV systems by about 75 percent, could decrease compliance costs.[32] In the models, between present day and 2030, the evolution of the power system was dominated by the implementation of aggressive energy efficiency measures and the installation of renewable energy and gas-fired generation facilities that replaced coal-fired generation. Post-2030, the models showed the electricity system undergoing a radical transformation that eliminated almost all carbon emissions from the generation mix. In the 2040 time frame, the models showed that deployment of wind, solar, and geothermal power displaced gas-fired generation, reducing overall power system emissions. In the 2050 time frame, not only did the models show that this deployment trend continued for wind and solar, but it was also accompanied by long-distance, high-voltage transmission capacity and large amounts of new storage. Such electricity storage was used primarily to shift solar energy availability to the evening, when it could be used to charge electric vehicles and meet demand from electrified heating.

[32] The SunShot Initiative is a national collaborative effort to make solar energy cost-competitive with other forms of electricity by the end of the decade (http://www1.eere.energy.gov/solar/sunshot/index.html).

The Benefits: These energy scenarios provided information on potential strategies to achieve California's long-term GHG emissions reduction goals. By anticipating the changes to California's energy system needed to meet those goals, results may be used to ease planning and guide investments in the energy system. For example, the results show that investments in energy efficiency and installation of renewables are needed under all scenarios to achieve the GHG reduction targets. Additionally, the results support early investments in new technologies, such as aggressive demand response and those that will help achieve the price target of $1/W for central station PV by 2020, to significantly reduce costs in the long term. They also may be used to anticipate negative environmental impacts of such changes and promote development of mitigation strategies in advance. Thus far, results have been used to inform the discussion of the future energy system in the climate change chapter of the Energy Commission's 2013 *Integrated Energy Policy Report* (*IEPR*). Specifically, the *2013 IEPR* indicates that the energy system is responsible for about 85 percent of the greenhouse gas emissions in California and that the electricity sector is particularly vulnerable to climate change impacts. The *IEPR* also includes discussion about post-2020 targets that benefitted from results made available from this project such as the need for electrification of energy services to achieve long-term deep reductions of GHG emissions. Additionally, this research contributed to the energy chapter of the draft 2013 update to the California Air Resources Board's *Climate Change Scoping Plan*.

Figure 18: Base Scenario Average Hourly Generation and Transmission Mix as a Function of Investment Period and Fuel in California



Source: Nelson, J et. al. 2013. California's Carbon Challenge Phase II Final Report.

Agreement Number: 500-10-047 Contractor: UC Berkeley
Project Cost: $900,000 Cofunding: $0 Project Term: June 30, 2011, to September 15, 2013

Energy Infrastructure Research

Why Today's Energy Infrastructure Needs Innovation

Since Thomas Edison designed the first electricity station in 1880, maintaining reliable electricity systems has become amazingly complex. The electric grid must connect generators of all sizes and types and transmit electricity of varying voltage across vast distances to diverse users, from manufacturing plants to mountain cabins. The grid is physically massive and fixed but must accommodate demand that fluctuates from one instant to the next. Electricity demand generally peaks on weekday afternoons during a summer heat wave, but historically the grid has needed the physical capacity to meet that demand year-round; expensive "peaker plants" that are used only during peak times must be built and maintained. These are merely a few of the existing challenges that faced yesterday's grid; entering a low-carbon, high-tech future requires the grid's very nature to evolve.

The electric grid was once a one-way system, with centralized plants using cheap, abundant fossil fuels to send power to users. Now, advancements in energy efficiency, renewable generation, and other energy areas depend on grid improvements. For example, increasing numbers of rooftop solar panels, other distributed renewable energy sources, and plug-in electric vehicles require the grid to flexibly manage power flowing both ways. Demand response technologies that prompt users to use less energy during peak periods make the grid more reliable, but they also require two-way communication between generators and users. Renewable sources like solar and wind have variable output, so the grid must also be able to store and use that energy on demand. Otherwise, low-output periods (like cloudy, windless days) could cause grid instability or blackouts. California's economy, safety, and environment depend upon these and other transformations of the electric grid.

The Energy Commission funds energy infrastructure research in multiple areas to support these goals. Research focuses on demonstrating key products and elements of the energy infrastructure, as well as the cost-effective integration of all new and emerging technologies and solutions that will build a smart energy infrastructure for California.

Research completed in the Energy Infrastructure Program involves a wider spectrum of research priorities and challenges than the previous two research areas. The research is focused on demonstrating not only key products and elements of the energy infrastructure, but the successful and cost-effective integration of all these new and emerging technologies and solutions.

The Project: Demonstrating the Benefits of Microgrids in Extreme Outage Events

The Issue: Microgrids have been demonstrated successfully for single customers but have not been designed and demonstrated across multiple customers as a utility asset. For utilities to adopt microgrids as an operating option, a utility microgrid needs to be designed and demonstrated to establish utility operational practices and show the benefits for multiple utility customers.

The Research: This project designed and demonstrated a microgrid operated by San Diego Gas & Electric Co. that incorporates sophisticated sensors, communications, and controls to explore microgrid islanding (disconnecting from the grid) of multiple customers along an entire distribution feeder. The Borrego Springs substation, with a peak load of nearly 14 MW, includes a microgrid composed of a single feeder with a 4 MW peak load. The microgrid successfully incorporated solar power generators on homes and businesses into the electrical delivery system, and it enabled coordinated demand response programs – including a price-driven program – that helped moderate electrical use during peak demand periods to prevent electrical supply emergencies. In addition, the microgrid integrated and controlled multiple distributed generation and electrical energy storage devices to operate the grid in a more cost-effective and reliable manner, benefiting customers and electrical rates. Overall, the Borrego Springs microgrid achieved a greater than 15 percent reduction in feeder peak load and improved system reliability.

Figure 19: Borrego Springs Microgrid

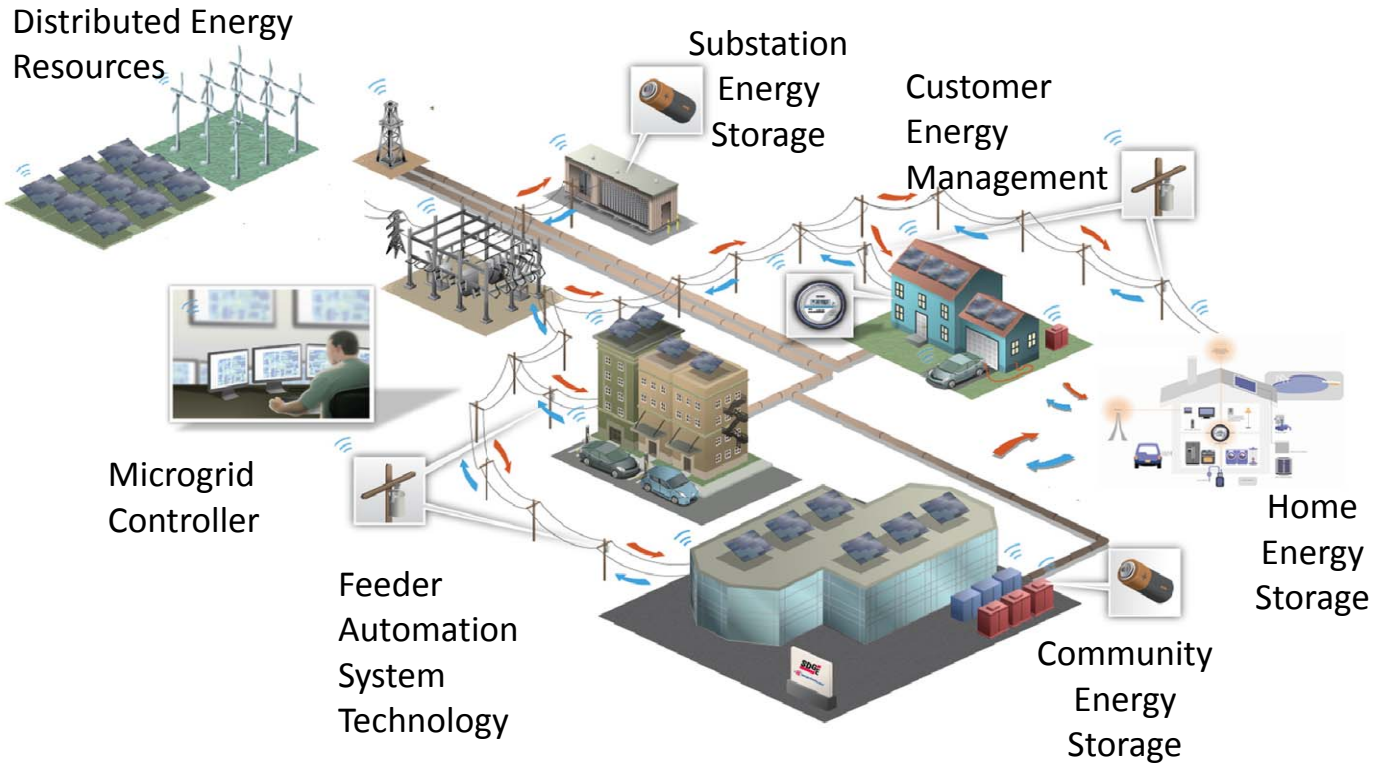


Figure 19 shows elements of the Borrego Springs microgrid, exemplifying the incorporation of energy storage, distributed renewable energy resources, and customer energy management, including demand response programs.

Source: SDG&E

The Benefits: In September 2013, the Borrego Springs microgrid – one of the world's largest and most complex microgrids – experienced a real-life test demonstrating its reliability when thunderstorms and flash floods knocked down transmission and distribution power lines, creating an outage affecting 2,700 customers. The microgrid was able to island and provide

power to more than 1,056 of the affected customers for more than 20 hours. *U-T San Diego* highlighted the importance of the microgrid in this event, stating that the microgrid is "a first of its kind in the area…a more robust, resilient grid that can dynamically react to the changing environmental and system conditions."[33] Such a grid can protect those in need during outages by supplying energy where there would otherwise be blackouts, possibly saving lives in the process. In addition to this event, the Borrego Springs microgrid also came into play after an April 2013 windstorm when it provided power for 1,225 customers for about six hours. After another outage event caused by a small flash flood in August 2013, the microgrid provided six customers power for five hours.

Through its leadership, San Diego Gas & Electric (SDG&E) successfully demonstrated the enhanced reliability a utility microgrid can provide to customers, and it has shown how a microgrid can operate as an alternative service delivery model for electricity utilities. According to Tom Bialek, chief of Smart Grid Engineering for SDG&E: "With the experience gained from operating the Borrego Springs Microgrid, the utility is designing and planning to install more microgrids across their territory. These smart grids will serve as additional pilots and as cost-effective alternative service delivery models, all of which is part of SDG&E's smart grid deployment efforts."

Figure 20: September 2013 Outage Event Aftermath (Left) and Next-Day Repair Crews (Right)

The figure on the left shows the aftermath from the September 2013 thunderstorm and flash floods, which knocked down transmission and distribution power lines, creating a major outage. Even though power lines were temporarily disabled, the microgrid continued to provide power to affected customers for more than 20 hours while crews repaired the damage the next day (right).

Source: SDG&E

Agreement Number: 500-08-025 Contractor: San Diego Gas & Electric

Project Cost: $2,808,488 Cofunding: $13 million, including a $6.18 million ARRA grant Project Term: May 18, 2009, to March 31, 2013

33 *U-T San Diego*. 2013. "Microgrid powers Borrego during emergency." http://www.utsandiego.com/sponsored/2013/nov/10/sgde-repair-crews-storm/.

Electric-Related Transportation Research

Transportation has the largest carbon footprint of any sector in California, accounting for nearly 40 percent of the state's total energy consumption. With more than 27 million registered vehicles in California consuming nearly 18 billion gallons of fuel annually, multiple state-level policies have been put in place to support advances in alternative fuels and vehicle technologies to reduce greenhouse gas emissions. In March 2012, Governor Jerry Brown issued an executive order directing state government to help accelerate the market of zero-emission vehicles including electric vehicles, with a goal of 1.5 million in California by 2025.[34]

Electric-related transportation research contributes to California's goals of reducing air pollution and greenhouse gas emissions, and it provides additional benefits that support efforts to improve grid services. Research will advance technologies that help address plug-in electric vehicle (PEV) integration and grid stability issues by developing advanced grid supporting capabilities, smart charging, demand response and energy storage. Innovative methods that successfully integrate PEVs have the potential to provide cost-effective and widespread solutions that can support the successful operation of California's power grid.

The Project: Putting Automotive Technologies to Work in California – The Plug-In Hybrid & Electric Vehicle Research Center

The Issue: As plug-in electric vehicles become a larger share of California's transportation market, it is important to ensure that the electrical load from charging these vehicles does not adversely impact the reliability of California's electric system. Current system impact research indicates that vehicle fleet electrification has the potential to increase total energy demand, alter peak load shapes, and increase demand on the transmission and distribution systems. The *Plug-In Hybrid & Electric Vehicle Research Center (PH&EV) Research Roadmap*[35] identified the following three areas of research to help ease the implementation of PEVs while managing potential grid impacts:

- Restructure the cost of PEV batteries: The primary impediment to large-scale commercialization of PEVs is the high cost of the vehicle batteries, making it difficult for PEVs to be cost-competitive in the vehicle market.
- Grid-connected vehicle integration: PEV charging and associated power systems that can effectively interact with a smart grid need to be further developed to prevent excessive and unmanaged PEV charging from affecting the reliability of California's electric grid.

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34 Governor Brown Zero-Emission Vehicles Executive Order. 2012. http://gov.ca.gov/news.php?id=17463.

35 Turrentine, Thomas. 2011. *Plug-In Hybrid Electric Vehicle Research Roadmap.* California Energy Commission, PIER Transportation Program. CEC-500-2010-039. http://www.energy.ca.gov/2010publications/CEC-500-2010-039/CEC-500-2010-039.pdf.

- Consumer Behavior: Conditions under which PEV owners most value their PEVs is uncertain. Research is necessary to better understand consumer charging behaviors such as responses to various electricity rates, interface designs, and smart-charging technologies.

The Research: The PH&EV Research Center, located at University of California, Davis, was developed to provide emerging transportation technology and policy guidance to the state and to help solve research questions, identify opportunities and constraints, and develop pathways to expanding California's PEV market. The PH&EV Center researched options for reducing the cost of lithium-ion batteries to help bring down the high upfront costs of PEVs, including opportunities for battery recycling and battery second use (repurposing batteries no longer suitable for use in vehicles into stationary storage devices). It has explored options for safely integrating PEVs into California's electricity grid and has researched consumer charging behaviors to better understand potential grid impacts of PEVs as the market evolves.

The PH&EV Center developed a model of a prototype system to determine the viability of repurposing used vehicle batteries into distributed energy storage devices and concluded that used PEV batteries are viable in stationary applications where power density requirements are lower than the previous automotive requirements and, in some cases, may achieve a similar performance to systems using new battery packs. Another method explored for reducing the high cost of PEV batteries is battery recycling, as California does not currently have established PEV battery recycling practices in place. Through a review and analysis of a variety of PEV lithium battery chemistries and recycling technologies available, the PH&EV Center determined that the most attractive lithium battery chemistries for recycling were those that contained higher levels of nickel and cobalt as they can be recovered using well-developed processes.

The center performed an analysis of the impacts of PEVs on California's grid and concluded that the addition of 1 million PEVs to California's transportation fleet would result in additional strain on the grid but not to a degree that would require significant upgrades.[36] The PH&EV Center also performed a series of case studies to evaluate the tools and information necessary for PEV drivers to optimize charging in a manner that meets drivers' needs while reducing potential strain on the grid. The case studies determined that consumers need access to key pieces of information to most effectively integrate their vehicles into the grid, including energy use by rate tier, the ability to receive rate tier data from utilities, and the ability to disaggregate PEV energy consumption from the home energy load. Provided this combination of data, PEV drivers will have the necessary information to establish optimized home charging routines that minimize the impacts of vehicle charging on the grid.

The Benefits: The PH&EV Research Center has effectively brought together a wide range of stakeholders, including utilities, vehicle manufacturers, and public and private entities, to

36 This analysis was limited to the transmission level and did not include an analysis of the grid at the distribution level.

address research needs and opportunities to promote California's PEV market information. The PH&EV Center's research has directly resulted in the identification of opportunities to reduce battery costs, such as extending the life of PEV batteries in secondary applications and recycling the batteries for reuse of valuable materials. Furthermore, research results not only indicated that California's grid (at the transmission level) could sufficiently absorb the additional load of 1 million PEVs without the need for significant upgrades, but they identified how the impacts of additional load from PEVs can be reduced through the development of stationary storage from spent PEV battery packs, as well as by optimized charging by PEV drivers.

Figure 21: Plug-In Electric Vehicle Charging

Source: UC Davis

Agreement Number: 500-09-041 Contractor: The Regents of the University of California, Davis
Project Cost: $2,780,000 Cofunding: $0 Project Term: June 21, 2010, to December 30, 2013

Energy Innovations Small Grant Program: Seeding Innovation and Market Success

In addition to large-scale demonstration projects, the Energy Research and Development Division manages the Energy Innovations Small Grant (EISG) Program that awards grants of up to $95,000 to test and evaluate new and innovative energy concepts and ideas. The following EISG project is an exceptional example of a just-started project that is an exciting technical solution. This project demonstrates the enormous possibility intrinsic in many of the smaller strategic investments made in the energy sector.

The Project: Facilitating Photovoltaics Using Ultra-Thin, Flexible, Ink-Based Technology

The Issue: Building-integrated photovoltaics are a substantial and growing market with tremendous opportunity for creating new renewable energy generating capacity. However, the market demands for a lightweight, reliable, and low-cost solar technology are not adequately met by currently available technologies.

The Research: Next Energy Technologies Inc. (NEXT Inc.) is developing an entirely new generation of organic photovoltaics (OPV) based on proprietary organic semiconducting inks made from soluble organic small molecules (SSMs). SSMs are low-cost plastic semiconductors that can be printed as an ink or spray coated directly onto conventional plastic sheets to fabricate inexpensive, lightweight, semitransparent, and flexible solar cells. The active layer of the NEXT Inc. solar cells is only 100 nanometers — 1/100,000th of a centimeter — thick, and it is

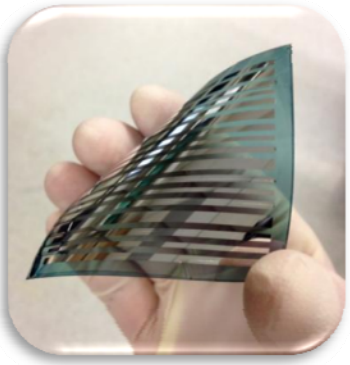
painted onto conventional rolls of plastic film. This is a very different form of solar energy compared to the flat, heavy panels used today. Moreover, capital costs to produce NEXT's solar cells are orders of magnitude cheaper than conventional PV, costing only between $5 million and $20 million per gigawatt peak compared to $1 billion for first- and second-generation solar panels. Researchers found that the soluble small molecules of the organic semiconducting inks at the heart of this OPV technology uniquely enable NEXT Inc. to overcome development barriers of earlier generations of polymer-based OPV.

This project is developing, synthesizing, and testing new semiconducting inks to design better materials and further improve morphological stability and efficiency. Even more, results are showing 5- to 30-year lifetimes and significant improvement in stability relative to competing polymer- based OPV in identical testing conditions.

The Benefits: NEXT's printable, ultra-thin, and transparent SSM-OPV coatings will have the potential to deliver exceptional value to the architectural glass and building-integrated photovoltaic markets. The raw materials are inexpensive, abundant, and nontoxic; the cells are semi-transparent, flexible, and color-tunable; the ink-based processing is efficient, high speed, and suited to domestic manufacturing; and the overall system is stable with long lifetimes. Most importantly, NEXT's low-cost, long-lifetime solar cells can seamlessly integrate into building glass and roofing products, filling a gap in the current solar market. The results of this research will help enable the future of net-zero buildings in California, and, if widely adopted, this technology could help the State of California meet important energy and environmental goals, including Assembly Bill 32 climate goals and the state Renewables Portfolio Standard.

NEXT Inc. expects to commercialize its technology in 2015. Following this research, NEXT Inc. received additional funding support from the National Science Foundation, the U.S. Department of Energy, and industrial partners.

Figure 22: NEXT's Flexible and Semitransparent Solar Material



NEXT's photovoltaics are printable, ultra-thin, and transparent materials. The flexible cells have the potential to deliver exceptional value to the architectural glass and building-integrated photovoltaic markets.

Source: Next Energy Technologies Inc.

Agreement Number: 500-98-014 Contractor: NEXT Energy Technologies Inc.
Project Cost: $95,000 Cofunding: $0 Project Term: November 1, 2012, to March 31, 2014

CHAPTER 3:
Benefits to California

Public interest energy RD&D projects funded by the Energy Commission achieve ratepayer benefits, ranging from reduced greenhouse gas emissions to reduced energy costs. These benefits to California not only provide the ratepayer with cleaner, cheaper energy and accessible innovative technologies, but they advance the state's energy policy goals.

This chapter includes excerpts of in-depth analyses of the benefits of various research efforts in important areas. These retrospective benefits evaluations discuss current savings provided by technologies previously supported by Energy Commission research, including components of these benefits that are directly attributable to PIER's role. Following the analysis section, the current and projected future benefits are described for the overall PIER 2013 research portfolio.

In-Depth Analyses of Technology RD&D and Its Ratepayer Benefits

The Energy Commission conducts in-depth analyses of the benefits provided by select advancements in energy technologies. Many PIER-funded projects have benefits that unfold for years following the actual funding of the project, producing continuous benefits in areas including jobs and energy produced and saved. Projects from 10 to 15 years past are still thriving today, and it is vital to understand the extent to which their benefits are serving California.

The Project: Efficient and Environmentally Friendly Winemaking

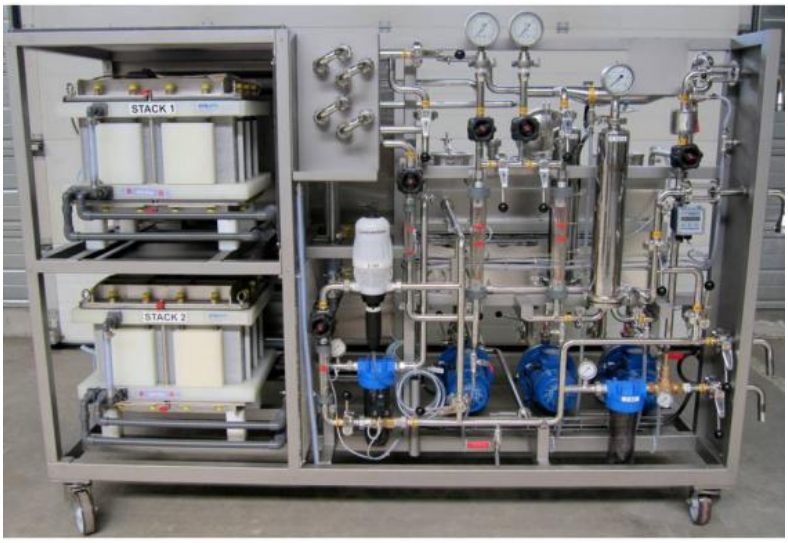
The Background: The Energy Commission funded Winesecrets' demonstration of a low-energy tartrate removal system for wineries in 2002, and from the beginning it was apparent that this project was a technological success. Twelve years later, the technology continues to advance, and even more, it is a market success as well.

An essential part of winemaking is removing undesirable tartrates, a process that traditionally requires energy-intensive and time-consuming cold storage, called *cold stabilization*. Winesecrets was founded in Napa in 2002 to bring a more environmentally friendly approach to California wineries, replacing cold stabilization with a less energy-intensive process. To accomplish this, Winesecrets uses the Selective Tartrate Removal System (STARS), which applies electrodialysis to more efficiently remove tartrates from wine. Specifically, STARS machines apply a weak electric field to charged and highly selective membranes. As the wine flows across these membranes, the electric field pulls the tartrates through the membranes, separating the tartrates from the purified wine. Finally, the tartrates are carried away by a brine solution.

STARS was initially developed and sold in Europe, with no vendors in North America at the time. Not only were start-up costs for new technologies intimidating, but North American wineries and winemakers were leery about the effects any new technology may have on their wine quality, especially considering the importance of flavor and tradition as selling points. In

2002, Winesecrets procured a STARS machine from France – the first one in North America – and created a mobile STARS unit with a grant of $309,757 from the California Energy Commission, matched by its own funds of $926,229. Winesecrets brought this unit to wineries to test the equipment on some of their wines, showing winemakers how the product would more than pay for itself by saving wineries energy, water, and business expenses, all while preserving wine quality. As a result, Winesecrets was able to commercialize STARS technology, providing full STARS units and installation services to large wineries and mobile services to smaller ones. As demand increased, the European manufacturer set up its North American sales office in Napa to collaborate with Winesecrets, now located in nearby Sebastopol. In the decade since the Energy Commission funded the demonstrations, mobile services have increased and larger units have been purchased in 10 large wineries in North America, half of which are in California. Winesecrets mobile services have been provided to 60 wineries in California's Central Valley, Central Coast, and North Coast, and to about 20 wineries outside California.

Figure 23: Winesecrets' Electrodialysis Machine



The stacks on the left contain cationic and anionic membranes to remove tartrates from the wine. Pumps and tubing on the right circulate wine, water, and brine with gauges to verify pressures are correct. The white container in the middle controls dosing.

Source: Winesecrets and Oenodia

The Benefits: Today, STARS units process 5 million gallons of wine a year in California, saving 4 million kWh of electricity and 1 million gallons of water, as well as reducing waste sodium hydroxide, sulfuric acid, and salt in the effluent water. In addition, this process prevents 38,000 gallons of wine from being lost due to tartrate removal, and more than 12,000 therms of natural gas are saved because there is no need to warm wine back up for bottle labeling.[37] Thanks to the

37 When wine undergoes cold stabilization, condensation from the cold temperatures builds up on the bottle, creating a challenge when adhering labels. After cold stabilization, many wineries have to warm wine bottles back up to near room temperature for labels to adhere properly.

STARS process, wineries are improving their net earnings by controlling when they release their inventory rather than having to wait through the weeks-long cold stabilization process. They are also saving on cold stabilization operational costs. All told, California winemakers are saving $1.5 million a year above STARS rental or purchase and operation costs independent of any utility incentives they may receive.[38] STARS machines in North America are processing around 9 million gallons of wine a year, preventing nearly 3,000 metric tons of carbon dioxide equivalent greenhouse gas emissions per year.

Based on sales growth and current negotiations, at least 3 million gallons of additional wine are projected to be processed per year in North America using STARS. If California's 56 percent share in STARS wine processing remains constant, this will remove 13 million kWh of electricity consumption from the California grid and will save California wineries $5.3 million a year by 2020. Under this scenario the present value of ratepayer net benefits from 2013 through 2020 would be $17.8 million, which is 57 times what the Energy Commission invested. If sales stopped today, the present value of operating existing STARS machines in California through 2020 is $8.7 million, 28 times the Energy Commission's investment.

These ratios represent the benefit-to-cost ratio of the Energy Commission's investment, given that Energy Commission funding was critical to obtaining these benefits. According to cofounder and co-owner of Winesecrets Domingo Rodriguez: "We came out of nothing with support from the Energy Commission and have rolled out in a major development with the support of utility companies across North America." Energy Commission demonstration support was needed because "private funds were not enough to fund a prolonged start-up of business to sell electrodialysis. Without the matching grant, we would not have been able to establish the business."

The Jobs: California jobs have been created in sales, rental, installation services, and the increased competitiveness of the California wine industry. Currently, 20 Californians are directly employed as a result of Winesecrets' dissemination of STARS. This business activity in California creates an additional 35 jobs due to purchases from suppliers and spending by employees.

38 This calculation assumes they borrow money at a rate of 8.75 percent.

Figure 24: Winesecrets' California Mobile Service Regions

This map depicts all the regions in California where Winesecrets provides its mobile services. In addition to California, Winesecrets has provided services in Oregon, Washington, Texas, and New York, as well as in Ontario and British Columbia in Canada.

Source: Winesecrets and Oenodia

The Project: Promoting Cost-Effective Solar With SunPower

The Background: In the 1980s, the Energy Commission funded a solar start-up whose vision was to increase solar energy's appeal through integration – integration of the various solar installation tasks and components into one cost-effective procedure, and integration of solar panels attractively into roofing materials. This start-up's work evolved into a new Berkeley-based company, PowerLight, which the Energy Commission funded $350,000 (matched by $620,000 from funding partners) in 1994 to design and test PowerGuard™, a solar photovoltaic roof tile. Four years later, the Energy Commission awarded PowerLight $960,000 to develop a high-volume manufacturing process for PowerGuard in California, and the following year in 1999, PowerLight was awarded an Energy Innovation Small Grant of $75,000 to further its solar roofing design. PowerGuard was a success, benefitting the California economy from 2005 through 2012 with $58 million worth of California-manufactured solar roofing sales, for which the Energy Commission has received $1.84 million in royalty payments.

In addition to the funding for PowerGuard, the Energy Commission awarded PowerLight $1.2 million in 2004 (matched by $1.7 million) to achieve a commercially successful design for an advanced solar PV tracking system named PowerTracker™. PowerTracker costs less to install than other trackers, and it increased solar electricity production 15 to 35 percent relative to stationary arrays. PowerTracker has generated $38 million in sales from 2007 through 2012, and it has produced $574,000 in royalties to the Energy Commission.

"The backing of the Energy Commission and other organizations allowed [PowerLight] to get across the 'Valley of Death' of commercialization," according to former PowerLight Vice President Melissa Zucker.[39] By 2005, PowerLight had 184 employees in California[40] and by 2007, PowerLight had more than 50 patents and was the primary seller of solar roofing products in the United States.[41]

PowerLight's largest solar cell supplier was the solar cell efficiency leader, San Jose-based SunPower (which was also a past EISG recipient). PowerLight was SunPower's largest customer as well, and in 2007, the two companies merged under SunPower. PowerLight provided its technologies and services along with the performance record needed to open up large-scale utility markets. SunPower noted in a postacquisition quarterly report that PowerLight had grown primarily because of the PowerGuard and PowerTracker products, and SunPower expected PowerLight to "accelerate product innovation" and "radically simplify and improve customer experience." [42] It also noted that PowerLight's SunTile™, a solar roofing product funded as part of an Energy Commission award to the Sacramento Municipal Utilities District, provided aesthetics and simple installation that would synergize perfectly with SunPower's PV production. SunPower's revenues rose from $243 million in 2006 to $340 million in the first three quarters of 2007 as a result of the acquisition, again supporting the California economy.

Following the merger, the PowerTracker developed into SunPower's T0™ and T20™ trackers,[43] and by 2011 there were more than 450 MW of commercial installations.[44] SunPower used the tracker to develop 250 MW of solar electricity in PG&E's California Valley Solar Ranch (totaling 550 million kWh of energy per year),[45] and it is building 579 MW of capacity (1.56 million MWh

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39 "Growth in the Green Economy: PIER Contributes to Job Growth and Private Investment." California Energy Commission. CEC-500-2011-048-BR.

40 PowerLight Corporation. *Tracking the Sun for High-Value Grid Electricity*. California Energy Commission, Public Interest Energy Research Program, 2006.

41 SunPowerFiling regarding purchase of PowerLight. Filed by SunPowerCorporation Pursuant to Rule 425 Under the Securities Act of 1933 And Deemed Filed Pursuant to 14a-12 Under the Securities Act of 1934. Subject Company: SunPower Corporation Commission File No.: 000-51593

42 United States Securities and Exchange Commission. 2007. "FORM 10-Q: SunPower Corporation." http://apps.shareholder.com/sec/viewerContent.aspx?companyid=SPWR&docid=5527742.

43 The T0 and the T20 trackers use the PowerTracker patent number (6058930), as noted in "Sunpower™ T20 Tracker: The Planet's Most Powerful Tracker." sunpowercorp.com. Document #001-56702 Rev**/LTR_EN/ November 2009.

44 Environmental Business International, Inc. 2011. *The Clean Energy Industry in California: An Economic Analysis Assessing the Current Market in the Global Economy*. California Air Resources Board.

45 SunPower Corporation's California Valley Solar Ranch. http://www.californiavalleysolarranch.com/ and Environment News Service. 2008. "California Utility Mainstreams Solar Photovoltaic Power." http://www.ens-newswire.com/ens/aug2008/2008-08-15-094.html

per year) for SCE's Solar Star Projects in Antelope Valley,[46] the world's largest solar ranch. Together, these projects created 1,350 local construction jobs and 55 long-term jobs, and the California Valley Solar Ranch project has attracted $2.5 billion of venture capital investment from Warren Buffett's MidAmerican Energy Holdings Company.

Figure 25: SunPower California Valley Solar Ranch Project (Left) and Aerial View of Solar Star Projects in Kern and Los Angeles Counties (Right)

Source: SunPower Corporation

SunPower's tracker solar devices are also applied on the smaller scale, with a total of 38 MW installed in California. For example, a 3.8 MW carport in Palm Desert will provide two-thirds of the electricity at College of the Desert.[47] Other installations include University of California, Merced (1.1 MW), the Western Riverside County Wastewater Authority (1 MW), Alameda Public Works (252 kW), the U.S. Post Office in San Francisco (205 kW), and various community college campuses. These installations can be estimated to save 64 million kWh of electricity per year.[48]

The residential PV market has also transformed with SunPower's technology, most considerably through its work performed under the $2.7 million Zero Energy New Homes (ZEN Homes) contract from 2005 to 2009. Before this project, new home developers generally resisted installing PV because of market barriers like high initial costs and disruption to production schedules. The ZEN Homes project helped SunPower develop a successful solar new homes marketing program by creating financing or leasing options that dropped the incremental first cost of solar homes to near zero. As SunPower states in its final project report:

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46 SunPower. 2013. "MidAmerican Solar and SunPower Start Major Construction on World's Largest Solar Power Development." http://us.sunpowercorp.com/about/newsroom/press-releases/?relID=137197 and "Status of RPS Projects," http://www.cpuc.ca.gov/PUC/energy/Renewables/index.htm.

47 SunPower Newsroom. 2013. "California's Community Colleges Go Solar With SunPower." http://newsroom.sunpower.com/2013-11-06-Californias-Community-Colleges-Go-Solar-with-SunPower

48 Calculations assume a 19 percent capacity factor, per the 2010 California Solar Initiative Impact Evaluation, conducted by Itron, Inc., for Southern California Edison and the CPUC.

> "Historically, new home developers and builders have resisted installing solar systems because of high initial cost, aesthetics, and lack of consumer demand. Residential solar and energy efficiency measures were largely installed as a construction afterthought by individual homeowners that were motivated to retrofit their existing homes. Few homes were actually built with integrated solar systems… [Builders] had many obstacles to overcome. Just four years ago, without the benefit of well defined standards, a fully developed solar marketplace, and energy efficient products, the challenges associated with building net zero energy new homes appeared insurmountable. That all changed when in June 2005, the California Energy Commission Public Interest Energy Research Program commissioned SunPower to conduct a study entitled, "Commercializing Zero Energy New Homes."[49]

Specifically, under the Energy Commission PIER funding, the ZEN Homes team gathered experts in homebuilding, home sales, energy, taxes, and solar law to develop procedures, rules, payment approaches, and legal materials, simplifying the path to solar for buyers and production home sellers. The ZEN Homes team also worked with regulatory agencies and businesses to streamline processing of permits and other essentials. Even further, under this contract SunPower developed the sleek SmartMount™ system to place solar PV panels on rooftops 30 percent more quickly, eliminating the need to deal with mounting rails or ground conductors between panels. Such improvements in technology, the permitting process, and cost led to homebuilders, buyers, and real estate professionals all reporting positive experiences, increasing the demand for solar installations in homes.

The project was not only transformational for SunPower, which developed contacts and a business model around leasing and selling PV in new residential developments, but also for all new residential construction. The ZEN Homes project showed homebuilders they could make solar work logistically, and even more, that they could get more customers in the door with solar than without. In the production home communities hosting ZEN Homes, SunPower demonstrated that solar homes sold twice as fast as the conventional ones, and 85 percent of solar customers listed saving on their monthly bills as a primary reason for their choice. In addition, more than 250 real estate agents and stakeholders and 850 homebuilder employees were trained, making SunPower the first solar provider to develop a dealer network.

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49 Galland, Matt; Kelly, Bill. 2010. *Commercializing Zero Energy New Home Communities*. California Energy Commission, PIER Renewable Energy Technologies Program. CEC-500-2014-007. http://www.energy.ca.gov/2014publications/CEC-500-2014-007/CEC-500-2014-007.pdf

Figure 26: SunPower Residential New Home Community

Source: SunPower Corporation

More than 270 homes with 587 kW of rooftop solar were installed during the ZEN Homes project, which adds up to a lifetime savings of 19 million kWh. In addition to the 270 homes installed under the ZEN Homes project, SunPower installed more than 3,300 systems by the end of the contract in 2009, and 6,000 systems remained in backlog. SunPower described these additional systems as "extended program benefits" in its final project presentation slides, noting that the ZEN Homes business model was "extended…into [the] entire SunPower New Homes division operations."[50] SunPower has become a fixture in production home sites, and now there are more than 26,000 residential SunPower systems (for a total of 172 MW) installed in 52 California counties. SunPower's photovoltaic systems produce 21 percent of the total electricity produced by residential PV systems,[51] saving more than 280 million kWh of electricity a year. Lastly, as intended, the integration of homebuilding and solar home sales has spilled over into the general marketplace, helping California reach toward its Million Solar Roofs Goal.

The Benefits: Total sales of SunPower systems through the California Solar Initiative (CSI) in IOU territories amount to 339 MW and generate 560 million kWh of electricity a year, generating $2.1 billion in sales revenues. By supporting tracker technology and residential market streamlining, Energy Commission grants directly contributed to 210 MW of these CSI supported sales, generating 350 million kWh per year of electricity and $1.35 billion in revenues.

Adding in the utility solar ranches, Energy Commission RD&D grants directly contributed to the installation of 1,040 MW of SunPower solar capacity, generating 2.46 million MWh a year. In addition, 800,000 metric tons of carbon dioxide emissions are offset annually, the equivalent of taking more than 100,000 cars off the road.

Not counting utility generation, the ratepayer benefits of SunPower's sales in California investor-owned utility territories are estimated to have a present value of $1 billion, or $100

50 Galland, Matt; Kelly, Bill. 2010. *Commercializing Zero Energy New Home Communities*. California Energy Commission, PIER Renewable Energy Technologies Program. CEC-500-2014-007. http://www.energy.ca.gov/2014publications/CEC-500-2014-007/CEC-500-2014-007.pdf

51 Using California Solar Initiative data from January 4, 2014, available at http://www.californiasolarstatistics.org/.

million a year, assuming a 25-year solar cell lifetime and an 8.75 percent discount rate. This is the value to consumers of the SunPower cells above all solar cell costs including CSI subsidies.[52]

Figure 27: California Counties With SunPower Technology

This map depicts all the counties in California where SunPower purchases have occurred, as recorded through the California Solar Initiative.

Source: California Energy Commission

The Jobs: SunPower and its partners' operations are directly sustaining 4,055 California jobs in addition to 800 construction jobs created in school and similar-sized installations each year, and 1,350 temporary utility-scale construction jobs. The sustained jobs include 100 in a manufacturing facility in Milpitas, 100 in SunPower offices throughout California, 800 in the San Jose and Richmond headquarters, 3,000 with SunPower's 200 independent dealer partners selling systems in 54 counties, and 55 positions in oversight, operations, and maintenance of utility solar ranches. These jobs create additional employment as firms and their employees buy goods and services. Staff estimates total effects to be 10,900 sustained jobs, as well as a temporary 3,500 job boost to local economies near the solar ranches in San Luis Obispo County and Antelope Valley.

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52 Staff aggregated sales by ZIP code and created a demand curve using statistical regression to estimate per capita effective kW installed as a function of the real price faced by consumers, a ZIP-specific socioeconomic status score from CalEnviroScreen, and the consumers' electricity use sector. Staff used the demand curve to estimate consumer surplus, the amount consumers would be willing to pay for SunPower PV minus the amount they and CSI paid. *Consumer surplus* is the standard measure of economic benefits to consumers used in benefit-cost analysis. Since consumer surplus estimates may be biased downward by the ability of local sales to influence local prices, staff also performed a two-stage regression. In the first stage, before aggregation and the estimation of the demand curve, staff estimated supply price as a function of the number of inverters, the number of modules, the year of installation, and which SunPower PV model was installed. The estimate of supply price was then used in the demand regression, per standard practice. The estimates of present value from the one-stage and two-stage approaches were $0.9 billion and $1.2 billion, respectively, with a 95 percent confidence interval of $0.5 billion to $3 billion for the one-stage model and a 94 percent confidence interval of $0.4 billion to $8.4 billion for the higher variance two-stage model.

Overview of the Ratepayer Benefits of the 2013 PIER Portfolio

California ratepayer benefits of PIER-funded energy research are significant and diverse. The 234 PIER projects that were initiated, ongoing, or completed in 2013 (herein referred to as the PIER 2013 research portfolio) were categorized broadly by their benefits to identify pathways for analysis and themes for discussion, including:

- Saving energy.
- Reducing the infrastructure requirements of the electric grid.
- Reducing ratepayer costs.
- Reducing greenhouse gases and mitigating the impact of climate change in California.
- Conserving natural resources and protecting public health.
- Enhancing the reliability and quality of electric service.
- Stimulating economic activity and employment in California.

Many of these benefits can lead to others, producing a cascading effect. For example, energy savings provide cost savings for ratepayers. Cost savings for ratepayers strengthen California's economy. Energy savings also reduce greenhouse gas emissions and air pollutants by avoiding operation and construction of natural gas-fired power plants. Reductions in air pollutants, in turn, produce health benefits for ratepayers. Through this systematic approach, the analysis captures the interrelated ratepayer benefits pursued and achieved by PIER.

Estimating the quantitative ratepayer benefits of PIER projects is complex. Because roughly 60 percent of the PIER 2013 research portfolio consists of ongoing projects, it is not possible to provide quantitative estimates for the entire portfolio. Furthermore, while many projects achieved tangible technical successes, additional time is required to commercialize their results, gain market share against established competing products and practices, and provide long-term ratepayer benefits. The uncertainty surrounding the market success of these projects requires conditional assumptions to generate estimates of their benefits; these assumptions are included in the discussion, footnotes, and the appendices.

For a subset of PIER projects, the result of the research consists of a report, modeling tool, or other information resource for ratepayers, utilities, or policy makers. In these cases, benefits cannot be quantified until the effect of the information on future decision-making is determined. Instead, the analysis in this report focuses on the ratepayer benefits of the decision-making itself, which is supported by the project.

For the above reasons, quantified benefits estimates are focused on selected PIER projects. Despite these challenges, the available data strongly support the conclusion that PIER has achieved benefits substantially greater than the amount of ratepayer funds invested. To discuss the ratepayer benefits of all PIER projects active in 2013, the Energy Commission systematically classified projects by the following attributes:

Research Areas – components of the electricity system: Research areas reflect the distinct physical components of the electricity system. While most projects fall neatly into one category, some projects address the integration of new technology across two areas and other projects provide analysis relevant to the entire electricity system. The four research areas are as follows:

- **The Electricity Use research area** consists of all projects relating to the consumption of electricity by ratepayers. In total, there are 116 projects classified as related to electricity use in the PIER 2013 research portfolio, accounting for $93.7 million in PIER funding and $74.5 million in match funding, or 80 cents in match funding secured per PIER dollar awarded. Among the four research areas, electricity use is the largest by number of projects and PIER funding, which reflects the priority placed on energy efficiency and demand response in California's loading order. However, relative to the share of PIER funds committed, electricity use projects were matched by the lowest amount of funding among the four research areas. This reflects the comparatively weak private incentives for development of new products and information resources related to energy efficiency and demand response.[53] PIER's allocation of funds reflects the need for public funding to make up for relatively lower private RD&D in the electric use research area.
- **The Electric Generation research area** includes projects that involve any technology (whether owned by ratepayers, utilities, or merchant generators) that generates electricity, as well as projects that address or mitigate the climate change consequences of GHG emissions from electric generation. In total, there are 105 projects classified as related to electric generation in the PIER 2013 research portfolio, accounting for $76.8 million in PIER funding and $183 million in match funding. Every dollar of PIER funding committed was matched by $2.38 of funding from private, federal, and other sources.
- **The Electric Grid Systems research area** consists of all projects that transmit, store, or manage electricity. This area includes storage, microgrids, demand response, enhancements to transmission and distribution infrastructure, customer premise networks, and many other technologies to achieve "the smart grid." In total, 52 projects are classified as related to grid systems, accounting for $52.4 million of PIER funding and $285.8 million in match funding. Among the four research areas, grid systems ranks highest in its ratio of match funding, with every dollar of PIER funding matched by $5.46 of funding from private, federal, and other sources. This large ratio is primarily due to a handful of projects that also received American Recovery and Reinvestment Act (ARRA) funds from DOE for research on the smart grid and storage.
- **The Electric Transportation research area** includes all projects relating to improvements in the efficiency and economics of electric vehicles, vehicle-to-grid applications, and the role of electrification in the transportation sector to meet policy goals. Electric

53 Gillingham, Newell, and Palmer. 2009. "Energy Efficiency Economics and Policy." *Annual Review of Resource Economics*, Vol. 1, pp. 597 – 620.

transportation is designated separately from stationary uses of electricity because of the unique challenges and opportunities associated with transportation and the large quantities of primary energy consumed in the transportation sector. In total, 19 projects are classified as related to electric transportation, accounting for $22.9 million of PIER funding and $20.7 million in match funding. For every dollar of PIER funding committed, 90 cents in match funding was secured for transportation projects.

Because of overlap across the research areas for some cross-cutting projects, the numbers cited above do not sum. Overall, there were 234 PIER-funded projects active or completed in 2013, totaling $186.2 million in PIER funding and $426.9 million in match funding. For every dollar of PIER funding committed, it was matched by $2.29 from private, federal, and other sources.

Advancements – the means by which a project seeks to achieve ratepayer benefits: Every project pursues one or more advancements in the technical, economic, or environmental knowledge that will ultimately lead to ratepayer benefits. Examples include lowering the upfront costs of an energy efficient appliance, enabling biomass facilities to meet stringent oxides of nitrogen (NO_x) emissions standards, ensuring connectivity of demand response products with the grid, or improving the transfer efficiency of charging stations of electric vehicles. Projects within the same research area generally pursue similar advancements. Each advancement is linked to a benefit, though advancements with more than one benefit will appear multiple times throughout the chapter.

End Users – the intended people who will use the results of the research: These consist of the ratepayers, energy companies, or policy makers who will make use of the research to provide ratepayer benefits. While the end user varies across projects, all projects are consistent with the guiding principle of PIER, which is to fund research with significant potential for ratepayer benefits. For example, residential ratepayers are the end users of research to develop new demand response products, utilities and the ISO are the end users of research on how to best manage demand response resources, and policy makers are the end users of research on regulatory issues arising from demand response. The distribution of funding among categories of end-users of the PIER 2013 research portfolio is as follows:

- **Ratepayers:** Forty-nine percent of funding was allocated toward research whose primary end users are ratepayers. These projects attracted 35 percent of match funds.
- **Electricity Suppliers:** Twenty-two percent of funding was allocated toward research whose primary end users are entities connected to the supply of electricity, including utilities, merchant generators, independent transmission line owners, and the California ISO. These projects attracted 60 percent of match funds, which is indicative of comparatively larger private market interest in energy RD&D in products owned and operated by electricity suppliers, rather than ratepayers. To compensate for this, the largest share of PIER funds are allocated toward projects whose end users are ratepayers.
- **Policy Makers:** Twenty-nine percent of funding was allocated toward research whose primary end user is policy makers, particularly state agencies and local governments.

These projects attracted only 5 percent of match funding. This low level of match funding indicates the critical role that PIER funds play in supporting research to California policy makers whose decisions affect ratepayers. The information generated by PIER-funded research enables smarter decision-making that will promote greater dissemination of new technologies at lower cost and environmental impact.

For each of the seven benefits that are the subject of this chapter, the discussion will be summarized by a table that provides a synopsis of the ratepayer-benefiting advancements pursued by the 2013 PIER research portfolio. These tables are formatted as follows:

Table 3: Sample Table

Benefit	Research Areas	Advancements	Projects
This column provides the type of benefit.	This column lists the active research areas that include projects whose goals relate to the benefit.	This column lists the advancements sought by projects to achieve the benefit. They are organized by research area.	This column lists the number of projects pursuing each advancement.

Energy Savings

Energy efficiency has been one of California's leading energy policy priorities since the energy crises of the 1970s. The most tangible, direct benefit of energy efficiency for ratepayers is the money saved on their utility bills from reduced energy consumption. However, many other benefits accrue to all ratepayers as a result of those who make energy efficient choices:

Energy efficiency strengthens the economy: According to a UC Berkeley study of the economic impact of California's energy efficiency standards, for every job in the electricity supply sector lost by energy efficiency, 50 new jobs are created in other sectors of California's economy as a result of the increased disposable income available to ratepayers.[54] Furthermore, energy efficiency improves California's balance of trade. A significant portion of California's electricity is imported, as is the fuel for a large fraction of in-state generation. Improvements in the efficiency of electricity production, delivery, storage, and consumption lower the need for energy imports. The money saved by California ratepayers as a result of efficiency is much more likely to be spent in California than money paid to energy suppliers located outside the state. Furthermore, efficiency improvements reduce economic vulnerability to supply disruptions and fuel price volatility.

Energy efficiency protects the environment and public health: While California is investing heavily in a clean energy future, natural gas-fired generation will remain a substantial fraction of the state's electricity supply in the near term. Reductions in inefficient electricity use reduce the need for fossil fuels, reducing their impacts on the environment and public health.

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[54] Roland-Holst, David. 2008. *Energy Efficiency, Innovation, and Job Creation in California*. Center for Energy, Resources, and Economic Sustainability (CERES), Department of Agricultural and Resource Economics, UC Berkeley. http://www.nextten.org/research/research_eeijc.html

Energy efficiency lowers the barriers to California's clean energy goals: To meet California's clean energy goals, alternatives to fossil fuels must be adopted. Unmitigated growth in energy demand will require larger investments in zero-carbon energy sources. By promoting efficient ratepayer consumption, energy efficiency reduces the need for these alternative energy sources, allowing policy goals to be achieved sooner and at a lower upfront cost.

Table 4: PIER Advancements to Save Energy

Benefit	Research Areas	Advancements	Projects
Energy Savings	Electricity Use	Efficient ratepayer consumption	80
		Strengthening of energy efficiency standards	24
	Electric Generation	Improved efficiency of electric generation	22
		Capturing and using waste heat	14
		T&D losses avoided by distributed generation	30
	Electric Grid Systems	Enhanced grid management to reduce T&D losses	8
		Smooth ramping to avoid inefficient generation	6
	Electric Transportation	Improved efficiency of electric vehicles and charging stations	2

Source: California Energy Commission

Overall, there were 118 projects that pursued one or more approaches to benefit ratepayers with energy savings. These projects accounted for 54 percent of total PIER funding and 64 percent of total match funding, respectively. Of these 118 projects, most were concentrated in the electricity use research area, accounting for two-thirds of the PIER funding spent on projects with potential to produce energy savings. Some of PIER's exemplary energy-saving projects from 2013 are discussed earlier in Chapter 2.

The first of these projects, *Aerosolized Sealant for Building Envelopes*, could result in substantial energy savings related to heating, ventilation, and air conditioning (HVAC) in the commercial and residential sectors. This project was selected for further analysis due to its technical achievements and strong potential for commercialization. If this process were applied to 1 percent of all homes and businesses in California beginning in 2016, followed by an additional 1 percent each year through 2024, ratepayers would save a cumulative 3.2 million MWh of electricity and 236 million therms. After the upfront cost of the treatment, the cost of financing, and the cobenefits of natural gas savings, the net benefits to ratepayers equate to roughly $765.9 million in 2013 dollars.[55] Over a conservatively assumed 10-year product life, the benefits exceed the costs by a ratio of 11 to 4. Because the longevity of the energy-saving effect remains to be determined, the realized benefits are likely to be even higher over the long term. The upper bound of potential ratepayer savings exceeds $1.5 billion per year, if all residential and commercial building envelopes were treated with aerosolized sealant.

55 See Appendix B for details and discussion.

To assess the potential energy saving benefits of a wider set of projects in the electricity use research area, data were collected and analyzed to estimate energy savings resulting from products, practices, and building designs developed by PIER projects. Table 5 displays the measured annual energy savings realized by demonstration projects active in 2013. For these 12 projects, the energy savings total 51 (±1.6) million kWh of electricity and 61.6 (±2.1) thousand therms of natural gas per year. These energy savings correspond to avoided GHG emissions of 17.4 (±.5) thousand metric tons of CO_2e per year and are worth roughly $7.5 (±.2) million per year to ratepayers. The performance data from PIER-funded demonstrations will encourage the dissemination of new energy efficiency products and practices throughout California, leading to the much greater ratepayer savings than those described in Table 6.

Table 5: Energy Savings Achieved at Demonstration Project Sites

Project Name	Electricity Savings (kWh/yr)	Natural Gas Savings (therms/yr)	Data Source
Plug-n-Play Diagnostics and Optimization for Smart Buildings*	42,112,178	-	Estimate by award recipient based on one or more years of operation
Variable Airflow Management With Direct Expansion (DX) Computer Room A/C	390,000	-	
Personal Thermal Comfort System and Occupant Responsive Optimized HVAC	10,000	-	
Urban Heat Island Mitigation − Phase 2	530	7	
Demonstration of Field Effectiveness of Classroom Single-Zone VAV units	371	-	
Primary Effluent Filtration as Intermediary Wastewater Treatment Step	65,000 to 115,000	-	
Supercritical CO_2 Cleaning and Sterilization of Commercial/Industrial Textile	732,000	55,200	
Large-Scale Retrofit Project	570	53	Third-party estimate based on less than a year of data
Realizing Energy Efficient Lighting in California	2,154,366	-	Estimate provided in final project report
Zero-Net-Energy Commercial Retrofits	4,375,275	3,276	Modeling and analysis by award recipient
State Partnership for Energy Efficient Demonstrations (SPEED) 2011-2014	139,000 to 1,610,000	0 to 5,300	Estimate by award recipient for ongoing project
Novel Hydrodynamic Separation Technology for Wastewater Treatment	193,345	-	Estimate provided in project proposal

*The large energy savings realized in this project are attributable to the large scale of the project. The product was demonstrated in 252 Target stores throughout California.

Source: California Energy Commission

In addition to the measured savings from demonstration project, the Energy Commission developed estimates of annual energy savings that would be likely to occur by 2020. These estimates refer to projects with strong potential for successful commercialization. They are presented in Table 6. This table includes projects in both the applied research and development stages and later demonstration stages of research.

Table 6: Potential Statewide Energy Savings in 2020

Project Name	Market Penetration	Electricity Savings (GWh/yr)	Source, Notes, or Assumptions
Plug-n-Play Diagnostics and Optimization for Smart Buildings	10%	159.8	CEC staff estimate
Development of Diagnostic and Measurement and Verification Tools for Commercial Buildings	5%	476.9	Estimate by award recipient during project
Energy Plus Graphical User Interface	5%	787.6	
Efficient Electronics Through Measurement and Control	5%	148.8	
Education Software for Workforce Development	5%	182.1 to 364.3	Third-party estimate
Energy Efficiency in Small Server Rooms	1%	17.5	CEC staff estimate
Data Center Economizer Cooling With Tower Water	1%	20	
SeaMicro Volume Server Power Reduction for Data Centers	1%	54.4	Estimate by award recipient, during project
Improved HVAC Through Standards for Technician Instruments	1%	29.3	
State Partnership for Energy Efficient Demonstrations (SPEED) 2011-2014	1%	181.2	
Demonstration of Field Effectiveness of Classroom Single-Zone VAV units	1%	1.3	
Self-Audit of Wastewater Treatment Processes to Achieve Energy Optimization	1%	1.6	
Personal Thermal Comfort System and Occupant-Responsive Optimized HVAC	1%	16	
Title 24 Credit for Efficient Evaporative Cooling[56]	1%	25.6	
Small and Medium Building Efficiency Toolkit and Community Demonstration Program	1%	6.2	Estimate by award recipient in project proposal
Novel Hydrodynamic Separation Technology for Wastewater Treatment	1%	.32	
Improving Residential Programmable Thermostats	1%	9.1	Estimate by award recipient during project
Improved Audio-Video Efficiency Through Inter-Device Control	1%	3.5	
Evidence-Based Design and Operations for Commercial Buildings	1%	23.1	

These are estimates of the energy savings that would be achieved if the products, strategies, or knowledge developed by the respective project were purchased or used by the estimated percentage of the applicable statewide market by 2020.

Source: California Energy Commission

56 Additionally, this project is estimated to save around 520,000 therms.

For most projects in Table 6, the estimates assume conservatively that 1 percent of ratepayers for whom the technology is relevant will have adopted it by that time. Where better forecasts of market penetration are available, these are used to generate the estimates and are noted accordingly. The resulting estimates of energy savings for California ratepayers total 2,272 (±113) GWh of electricity and 52 (±2) thousand therms of natural gas per year. Energy savings of this magnitude would prevent the emission of 648 (±33.4) thousand metric tons of CO_2e per year and provide $375.5 (±18.7) million in utility bill savings to California ratepayers.

While ratepayer electricity use represents the largest opportunity for energy savings, PIER's research is diversified across the electricity system. Energy savings on the utility-side of meter indirectly pass on lower energy costs to ratepayers and provide societal benefits similar to ratepayer energy savings. Figure 28 summarizes the allocation of PIER funds toward energy-saving innovations by research area. The other research areas in which PIER projects are advancing energy-saving innovations include:

***Electric Generation*:** There are 35 PIER projects in the electricity generation research area that are promoting energy savings, accounting for 33 percent of PIER funding for all energy-saving projects. PIER projects in this research area are promoting energy-saving innovations by one or more of the following:

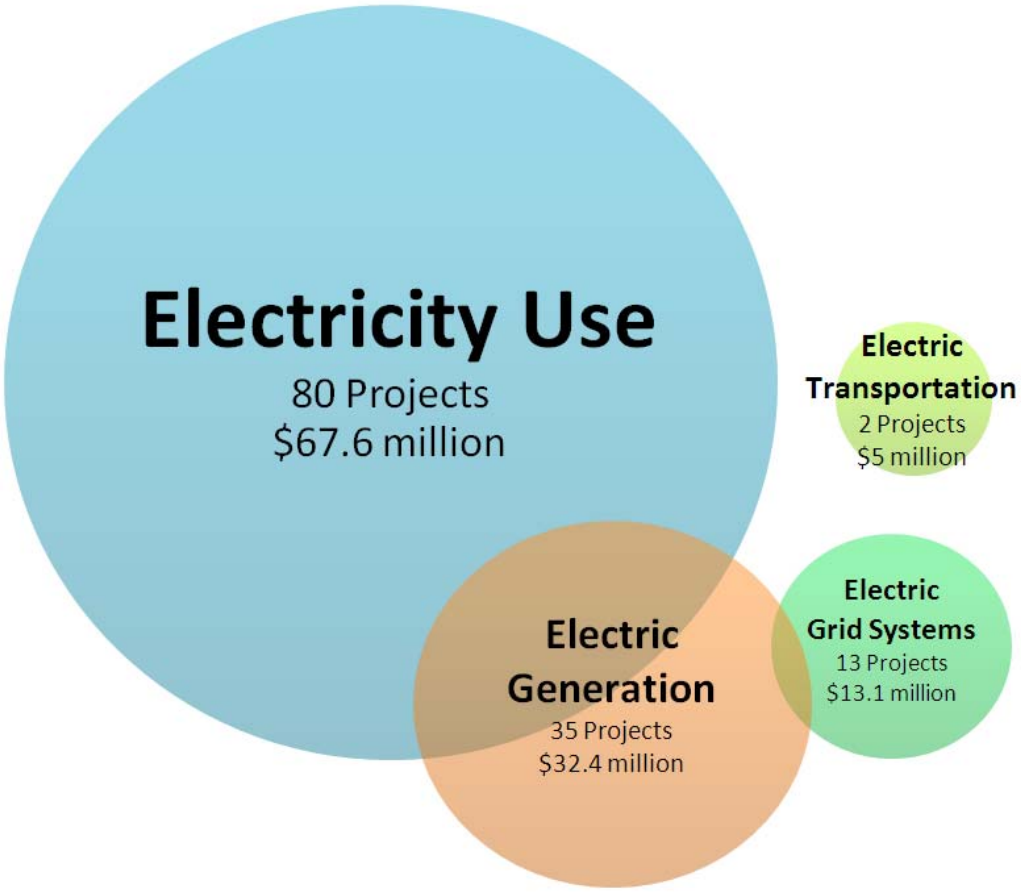
- Improving the efficiency by which fuel input is converted to electrical output, reducing primary energy consumption (22 projects).
- Capturing and using waste heat as part of an electric generation process, avoiding unnecessary demand for grid electricity and/or the use of on-site thermal equipment (14 projects).
- Avoiding transmission and distribution losses through the use of distribution generation, which provides electricity to ratepayers directly where they use it (30 projects).

***Grid Systems*:** There are 13 PIER projects dedicated to improving the efficiency of the management, storage, and delivery of electricity to ratepayers. They represent 13 percent of the funding for PIER projects to promote energy savings. PIER projects in this research area are promoting energy-saving innovations by one or more of the following:

- Enhancing management of the grid to reduce transmission and distribution losses (eight projects).
- Using innovative grid resources, such as storage and demand response, to smooth sudden "ramps" in electricity demand that would ordinarily be served with inefficient fossil fuel generation (six projects).

***Electric Transportation*:** There are two PIER projects dedicated to improving the efficiency of electric vehicles and charging stations. They represent 5 percent of the funding for PIER projects to promote energy savings.

Figure 28: PIER Funding for Energy-Saving Projects



The size of each circle corresponds to the PIER funding amount for projects in that research area that have potential to create energy savings. Overlapping areas represent projects that fall under both research areas. For example, projects relating to zero-net-energy buildings are classified as both Electricity Use and Electric Generation. Because of overlap, project counts and funding amounts do not sum to the exact total.

Source: California Energy Commission

Figure 28 reveals PIER funding priorities with respect to opportunities for energy savings. The predominance of electricity use research reflects the high priority placed on energy efficiency and demand response in California's loading order. Nevertheless, the figure also conveys the diversity of research conducted throughout the electricity system with respect to energy savings.

Reducing the Infrastructure Requirements of the Electric System

Because of California's sunny summer seasons, use of air conditioning represents a major driver of peak electricity demand. Periods of peak demand stretch the supply of electricity thinly and cause dramatic increases in the wholesale prices of electricity during peak hours. This summer peak in electricity demand has historically necessitated inefficient, natural gas-fired power plants that operate infrequently to ensure demand is satisfied at all hours. This form of

generation is relatively cheap to build, but expensive to operate. Investments in such plants and the transmission lines needed to connect them with customers are ultimately recouped at ratepayer expense. To minimize these costs, California's energy policy has pursued peak demand reduction in tandem with its overall energy efficiency goals. Furthermore, more recent developments offer tremendous potential to reshape the market dynamics that drive these capital expenditures. The PIER 2013 research portfolio has promoted these developments to reduce infrastructure costs for ratepayers:

***Storage*:** Historically, storage has been insignificant in the management of energy resources. Once transformed from primary energy, electricity has been prohibitively expensive to store on a large scale. Instead, the power output of electric generation must precisely match the rate of consumption (also known as load or demand) at all seconds throughout the day to ensure reliability. Affordable and efficient electricity storage could reduce many of the costs of peak demand by eliminating the need for generation to closely follow demand. The PIER 2013 research portfolio includes 23 projects that advance storage, 12 of which were devoted to ratepayer-owned storage.

As electric vehicles (EVs) rely on battery storage, there are opportunities to integrate EV batteries with the grid through vehicle-to-grid (V2G) applications. Linking EVs with the grid will simultaneously enable a large pool of storage resources to participate in electricity markets and reduced the total cost of EV ownership by bringing reduced utility bills to EV owners. There are three projects in the PIER 2013 portfolio dedicated to advancing applications for the interaction of EV batteries and the grid, including providing ancillary services that enhance grid reliability, integrating renewable energy, and reducing peak demand.

Demand Response: Demand response introduces another common feature of other energy markets that has not been historically prevalent in the electricity system. While the cost of generating and purchasing electricity varies dramatically throughout the day for utilities, the price of electricity paid by residential ratepayers remains constant. California has transitioned nonresidential customers to time-of-use rates, but residential ratepayers remain on time-invariant rates by default, unless they opt-in. Participation rates remain low.[57] Therefore, most residential ratepayers receive no financial benefits from shifting their electricity from peak hours to off-peak hours. Demand response technologies and utility programs not only enable ratepayers to capture those benefits, but they can provide even greater ratepayer benefits by allowing for close coordination with grid dispatch operations. The PIER 2013 research portfolio includes 22 projects that advance demand response, load shifting, and other strategies to optimize the timing of ratepayer electricity use to minimize cost. Of these projects, seven were applicable to the residential sector.

57 For example, around 2 percent of Pacific Gas and Electric's residential electric customers have enrolled in the utility's SmartRate program. ftp://ftp.cpuc.ca.gov/gopher-data/energy_division/DR/2013/PGE_Dec_2013.pdf

Distributed Generation: Distributed generation (DG) enables ratepayers to become their own electricity suppliers while reducing the need for transmission investments associated with central-station power plants. As with ratepayer-owned storage, ratepayer-owned DG reduces the need for capital expenditures by electricity suppliers and enables ratepayers to earn the financial returns on the investment instead. To lower strain on distribution equipment from surplus electricity exports by DG, PIER has been actively targeting research to facilitate bidirectional power flow. Overall, the PIER 2013 research portfolio includes 53 projects that advance distributed generation.

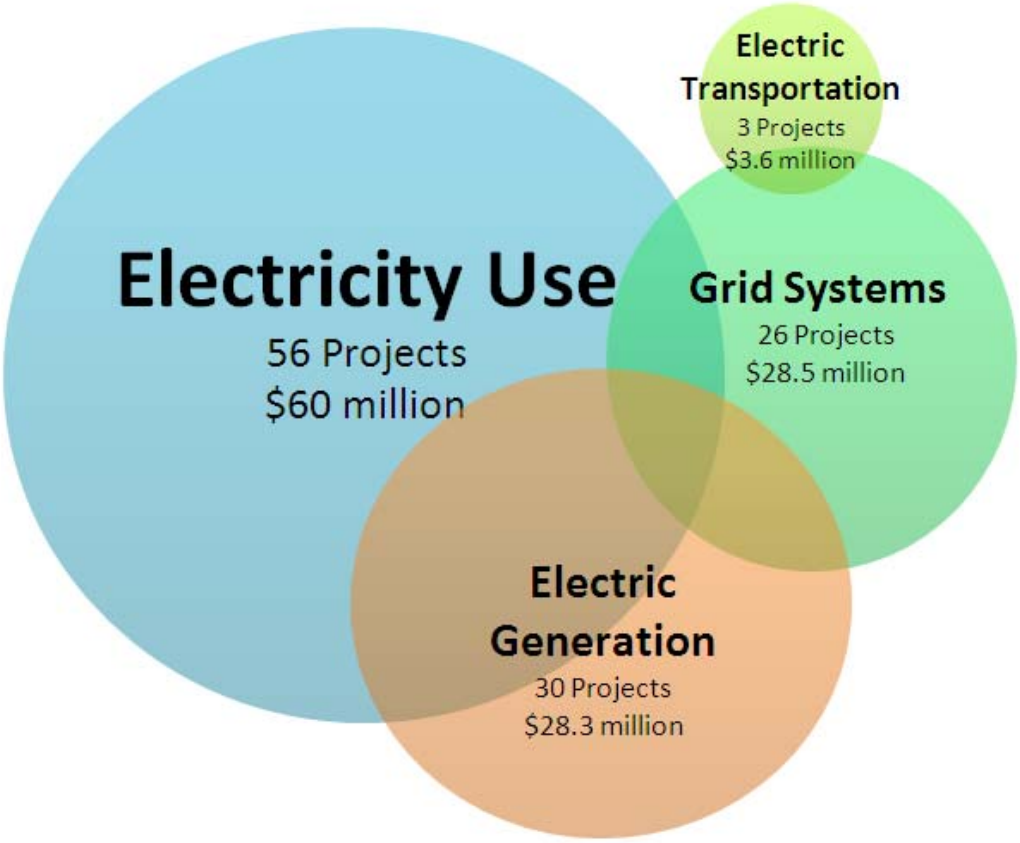
Table 7: PIER Advancements to Reduce Infrastructure Requirements of the Electric System

Benefit	Research Areas	Advancements	Projects
Reduced Infrastructure Requirements	Electricity Use	Peak demand reductions from energy efficiency improvements	48
		Demand response and load shifting to optimize ratepayer load profile	26
	Electricity Generation	Reducing need for back-up generation	9
		Reduced needs for transmission and distribution infrastructure	13
		Reduced net ratepayer peak demand through distributed generation	23
	Electric Grid Systems	Reducing peak demand through storage	23
		Enhanced grid integration of distributed generation	13
		Economized use of existing transmission and distribution assets	8
	Electric Transportation	Enabling vehicle-to-grid applications	3

Source: California Energy Commission

Table 7 provides more detail on the numerous advancements pursued by PIER projects to reduce the infrastructure requirements of the electric system. Many projects involve more than one way of reducing these costs, so the numbers within the table cannot be summed. Figure 29 below summarizes the distribution of PIER 2013 projects across the research areas as it relates to this issue. Overall, 97 projects of the 234 in the PIER 2013 research portfolio were identified as having potential to reduce or mitigate the supply-side infrastructure requirements of the electric system. Together, these projects account for $99.6 million in PIER funding and $283.1 million in match funding, or more than half of total PIER funding and two-thirds of match funding.

Figure 29: PIER Funding to Reduce Infrastructure Requirements of the Electric System



The size of the circles corresponds to the listed PIER funding amount for projects identified as promoting reduction in infrastructure requirements of the electric grid. Overlapping areas represent projects that fall under both research areas. Because of overlap, project counts and funding amounts do not sum.

Source: California Energy Commission

In addition to quantified energy savings, PIER 2013 projects have also realized quantified peak demand reductions in demonstration and have tremendous potential to reduce statewide peak demand. These are presented in Tables 8 and Table 9; the discussion of the methodology is available in Appendix B. Together, demonstration projects active in 2013 have achieved a total of 474 (±21) kW in peak reduction, worth around $57,600 (±2,600) in savings for ratepayers.

Table 8: Measured Peak Demand Reduction Realized in Demonstration Projects

Project Name	Peak Demand Reduction (kW)	Source
One-Cycle Control Peak Load Reduction System	15 kW	Contractor estimate based on at least one year of operation
Personal Thermal Comfort System and Occupant-Responsive Optimized HVAC	2 kW	
Urban Heat Island Mitigation Phase 2	.16 kW	
Enterprise Plug-n-Play Diagnostics and Optimization for Smart Buildings	276 to 340 kW	Contractor projection in final report
State Partnership for Energy Efficient Demonstrations 2011-2014	9 to 87 kW	Contractor projection during contract
Low-Cost, Scalable, Fast Demand Response for Municipal Wastewater and Recycling Facilities	100kW	

Source: California Energy Commission.

The estimates in Table 9 assume conservatively that only 1 percent of ratepayers for whom the technology is relevant will have adopted it by 2020. Under this scenario, the resulting peak demand reduction totals roughly 288 (±9.6) MW of electricity per year. Demand savings of this magnitude would produce $35 (±1.2) million in savings annually for ratepayers.

Table 9: Potential Statewide Peak Demand Reduction in 2020

Project Name	Peak Demand Reduction (MW)	Source and Assumptions
One-Cycle Control Peak Load Reduction	282.6	1 % of technical potential, estimate by award recipient
Personal Thermal Comfort System and Occupant-Responsive Optimized HVAC	5.4	

These are estimates of the peak demand reduction that would be achieved if the products developed by the projects listed were disseminated to 1 percent of the applicable statewide market in 2020.

Source: California Energy Commission.

Reducing Ratepayer Costs

California's energy goals represent a vision for the future that could not be achieved by private market forces alone. While the societal costs incurred by unabated fossil fuel use are large and continue to rise, the private costs of fossil fuel use have been substantially lower than most zero-carbon alternatives for centuries. As a result, private investment in the energy sector has

historically been concentrated on the exploration, extraction, processing, transportation, and use of fossil fuels, including RD&D to enhance productivity and drive costs even lower.

Table 10: PIER Research to Reduce Ratepayer Costs

Benefit	Research Areas	Advancements	Projects
Reduced Costs of Innovative Technology	Electricity Use	Ratepayer electricity savings	80
		Peak demand reduction	56
		Reduced costs of energy-efficient choices	31
	Electric Generation	Reduced cost of electricity generation	8
		Reduced cost of achieving AB 32 goals	18
		Reduced cost of waste disposal	10
	Electric Grid Systems	Improved use of existing assets	8
		Reduced cost of smart grid assets	6
		Automated diagnosis of equipment condition	8
	Electric Transportation	Reduced cost of electric vehicles	4
		Reduced fuel costs through fuel switching	19
		Second-life uses for electric vehicle batteries	5

Source: California Energy Commission

The historical dominance of fossil fuels in energy markets has shaped not only the collective decisions of markets for energy production, but markets for energy use, grid systems, and transportation. The position of fossil fuels as the least-cost fuel source has been important in driving private investment decisions in these markets as well.

By contrast, historically, the business case for private investment in RD&D for renewable energy has been limited by the well-established market position of fossil fuels. To promote an increased dissemination of renewable energy in California's energy markets, renewable energy must not only be shown cost-competitive with fossil fuels to produce, but cost-competitive to deliver to ratepayers and integrate seamlessly into their modern lives. PIER has funded innovation in all four research areas to drive down the total cost of renewable energy and energy efficiency. Table 10 provides an overview of the cost-saving innovations of the PIER 2013 research portfolio across all research areas. Two specific examples of PIER's work to reduce the cost of renewable energy include:

- *Wind Ramp – Short-Term Event Prediction Tool – Development and Implementation of an Analytical Wind Ramp Prediction Tool for the CAISO*, conducted at UC Davis. This project builds on a previous PIER project that developed a data tool for the California Independent System Operator (California ISO) to predict sudden changes in wind generation. This project will further refine the tool and analyze historical data from wind resource regions in California to improve the accuracy and value of the information provided by the tool to the California ISO. As a result, the amount of quick-start back-up generation needed to integrate intermittent wind energy into the electric grid will be reduced, lowering ratepayer costs.

- *Waste Vegetable Oil Driven CHP for Fast Food Restaurants,* conducted by Altex Technologies Corporation. This project is working to develop a distributed CHP system that can meet stringent emission standards while remaining affordable. If successfully commercialized, the result will enable California fast food restaurants to save on utility bills through use of a renewable energy resource.

These cost reductions benefit the ratepayers who adopt new technologies for their own use, as well as other ratepayers who benefit from lower costs incurred by utilities to meet their statutory and regulatory obligations to minimize their environmental impact.

Addressing Climate Change

Research funded by PIER supports the central goal of California's energy policy, which is to address the increasing disruption to the Earth's climate caused by anthropogenic greenhouse gases. Primarily, PIER projects advance new technologies, strategies, and information that will promote the dissemination of zero-carbon alternatives to meet the state's energy demand. However, the Energy Commission recognizes that even as the world strives to reduce its climate impact, the legacy of past anthropogenic GHG emissions may be too large to completely mitigate. Therefore, some of PIER's research is dedicated to preparing for the future and benefitting ratepayers by minimizing the damage to California's economy, natural resources, and quality of life resulting from climate change.

PIER research in 2013 to reduce GHG emissions spans all four major research areas: electric use, electric generation, electric grid systems, and electric transportation. The electric generation category includes 14 projects to address the impact of climate change in California. These projects relate to carbon capture and sequestration and climate science, and they are classified in this category because of the large degree to which GHG emissions are historically attributable the generation of electricity. For example:

- *Investigation of Discrepancies in Regional Climate Projections for California,* conducted at University of California, San Diego. Past PIER research has shown that the electricity sector—including generation, delivery infrastructure, and consumption—is vulnerable to climate change. This project will ensure greater accuracy and consistency of forecasts to ensure appropriate planning of the future electricity system at minimum ratepayer expense.

Table 11: PIER Advancements to Address Climate Change

Benefit	Research Areas	Advancements	Projects
Addressing Climate Change	Electricity Use	Reducing fossil fuels consumption through energy efficiency	80
	Electric Generation	Advancing renewable generation resources	95
		Advancing carbon capture and sequestration	5
		Verifying GHG emissions data	6
	Electric Grid Systems	Advancing storage to integrate intermittent renewable energy	30
	Electric Transportation	Advancing low-/zero-emission electric vehicles	19
		Using electric vehicles to integrate renewable energy	3

Source: California Energy Commission

Based on quantitative estimates of energy savings from energy saving projects presented earlier in this report, it is possible to estimate reductions in greenhouse gas emissions from California's electricity system. For example, modest adoption of aerosolized sealants for building envelopes presented earlier in this chapter would avoid a cumulative 2.2 million metric tons of carbon dioxide and other greenhouse gases between 2016 and 2024, inclusive. The energy savings of PIER projects estimated earlier in Table 6 would reduce CO_2-equivalent GHG emission by 652 (±36.5) thousand metric tons in 2020, if the estimated levels of market penetration were achieved.

Natural Resource Conservation and Public Health

In addition to addressing the threat of global climate change, California's energy policies include goals to protect the state's fresh water supply, air quality, flora and fauna, scenic beauty, and public health from the environmental impacts of energy use. Energy Commission research has studied energy-related environmental impacts and advanced clean energy solutions to address them. PIER projects active or completed in 2013 that support these environmental goals occur across the research areas of electricity use, electric generation, electric grid systems, and electric transportation.

Table 12: PIER Advancements to Conserve Natural Resources and Protect Public Health

Benefit	Research Areas	Advancements	Projects
Natural Resource Conservation & Protection of Public Health	Electricity Use	Reduced criteria pollutant emissions through energy savings	80
		Water conservation	11
	Electric Generation	Advancing renewable generation	95
		Avoiding landfill waste	13
		Reduced criteria pollutant emissions per kWh	3
		Reduced impact on water resources	7
		Reduced land-use and habitat impacts	24
		Anticipating and mitigating impact of climate change on California's environment	18
	Electric Grid Systems	Reduced criteria pollutant emissions through energy savings	13
		Enabling greater penetration of renewable energy	30
	Electric Transportation	Reduced criteria pollutant emissions through electrification of transportation	19

Source: California Energy Commission

In total, 11 projects in the PIER 2013 portfolio were identified as conserving water resources. These projects include efficient building designs that conserve energy and water simultaneously, novel wastewater treatments that slash energy requirements and enable new sources of water recycling, and energy-efficient industrial processes that coincidentally eliminate the need for water altogether. One project in particular, *Demonstration of i50 Decentralized Wastewater Treatment/Water Recycling*, is taking bold steps to address the water-energy nexus. Los Angeles-based Great Circle Industries is demonstrating its proprietary waste

water treatment technology at a facility of the Dublin San Ramon Services District. This technology can be transported directly to where water is needed and connected to a nearby sewer line. Drawing and treating wastewater, it can yield water suitable for irrigation in agriculture and other applications. The project has the potential of reducing the embedded energy in water associated with water treatment and transport; reductions in electricity could exceed 50 percent. By enabling new low-cost, energy-efficient water treatment options, the use of water treatment will grow and help address California's water shortage.

In addition to conserving water, PIER research also has benefits for air quality. In 2005, criteria pollutants from combustion sources in the electric power sector are estimated to have caused approximately 476 premature deaths in California. [58] Based on quantitative estimates of electricity savings presented earlier in this chapter, it is possible to estimate reductions in criteria pollutant emissions from power plants in California. From 2016 through 2024, the previously discussed scenario of market penetration of aerosolized sealants for commercial and residential building envelopes would avoid roughly 55.5 metric tons of nitrogen oxides (NO_x), 7.93 metric tons of sulfur oxides (SO_x), and 23.8 metric tons of directly emitted fine particulate matter ($PM_{2.5}$). In 2020 alone, the total electricity savings estimated earlier in Table 6 correspond to annual reductions in NO_x emissions by 39.5 (±2.2) metric tons, SO_x emissions by 5.6 (±.3) metric tons, and $PM_{2.5}$ by 16.9 (±.9) metric tons.[59]

Enhancing Grid Reliability and Power Quality

California ratepayers require reliable, high-quality electric service to power a modern standard of living. A study by Lawrence Berkeley National Laboratory estimates that the typical small business suffers an economic loss of $314 from a momentary interruption of electric service and $665 for an outage lasting one hour.[60] To promote reliability and quality improvements throughout the electricity system, PIER conducts relevant research in all four research areas. However, the focus of this research rests primarily on electric grid systems. Of the 52 total projects in this research area, 49 include reliability among their benefits. Table 13 overviews the PIER 2013 projects with potential to contribute to the reliability and quality of electric service for ratepayers.

58 Caiazzo, Fabio, et al. 2013. "Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005." *Atmospheric Environment* Vol. 79, pp. 198-208.

59 See Appendix B for sources, assumptions, and calculations.

60 Dollar values are adjusted using the GDP deflator to present estimates for 2013. Source: Sullivan, Michael J. 2010. *How to Estimate the Value of Service Reliability Improvements.* Lawrence Berkeley National Lab. LBNL-3529E. http://certs.lbl.gov/pdf/lbnl-3529e.pdf.

Table 13: PIER Advancements to Enhance Grid Reliability and Power Quality

Benefit	Research Areas	Advancements	Projects
Grid Reliability and Power Quality	Electricity Use	Using demand response to provide ancillary services	6
	Electricity Generation	Promoting grid integration of new generation resources	30
	Electric Grid Systems	Reduced risk of transmission or distribution outages	12
		Quicker outage restoration	8
		Restoring service without sending out technicians	8
		Ensuring uninterruptible power supply for high-priority facilities	7
		Promoting microgrids capable of islanding from the grid	9
		Enhanced management capabilities for grid operators	16
	Electric Transportation	Integration of electric vehicle batteries to provide ancillary services	3

Source: California Energy Commission

Stimulating Economic Activity and Employment

As discussed throughout this chapter, the PIER research portfolio provides numerous and often interrelated benefits to California's ratepayers. This section discusses additional economic benefits not mentioned earlier. One noteworthy economic benefit of PIER is the extent to which it reinvests ratepayer funds into California's economy. Of the 234 projects active or completed in 2013, 218 were carried out by researchers primarily located in California. About 94.4 percent of PIER funding and 95.5 percent of match funding were allocated toward these 218 projects. Of those projects conducted primarily by researchers located outside the state, many included facilities in California where a new technology was installed and demonstrated.

Table 14 tabulates the direct employment of California workers resulting from PIER funding for projects active in calendar year 2013. These numbers include employment over the lifetime of each project; the average project lasted about 3.2 years. In total, an estimate 2,545 California workers were directly employed, either full- or part-time, by the PIER 2013 research portfolio. The total number of hours worked is equivalent to roughly 1,503 person-years[61] of full-time work. Over their entire duration, these projects will pay an estimated $103 million in wages and benefits to California workers.

[61] One full-time-equivalent work year is approximated here to be 1,911 hours, which represents a 40-hour work week with 10 holidays and 12 days of other leave or vacation.

Table 14: Measures of Employment by PIER 2013 Projects in California

Measure	Estimate
Persons Employed, part or full-time	2,544
Years of Full-Time-Equivalent Work	1,503
Wages & Benefits Paid	$103 million

Note: Because about 60 percent of projects are still in progress, these estimates refer to budgeted values. Dollars are not inflation-adjusted.

Source: California Energy Commission.

PIER not only stimulates employment in California, but provides valuable experience and training to California workers. College students were included among the staff on 61 projects in California. Furthermore, a select group of projects were dedicated to green job training, such as the Smart Grid Workforce Clearinghouse at California State University, Sacramento, which not only better prepares California workers for future jobs, but enhances the quality of work performed on behalf of California ratepayers. Five projects involved developing standardized curriculum for green job training, while two projects directly conducted green job training for California workers. Overall, 79 projects were identified as having one or more positive impacts on development of the California workforce.

Another important indicator of PIER's future economic benefits to California is the jobs that will be created directly by the successful development and commercialization of new energy technologies. This is in addition to the economic growth resulting from all successful PIER-funded projects will indirectly create jobs in all sectors of the economy through cost savings, improved health, and avoided climate change damages for ratepayers. The discussion below considers direct employment in California's electricity-related sectors resulting from PIER research. These job estimates are preliminary, and the ultimate impact on employment will be determined by the commercial success of PIER-funded technologies in future years.

The Energy Commission identified 55 projects – accounting for $47 million in PIER funding and $268 million in match funding – as having the potential to create future, long-term jobs in California directly associated with the manufacture, sale, installation, maintenance, or operation of the technology. Of these, recipients of PIER funds for 14 projects, accounting for $10.6 million in PIER funds and $38.4 million in match funds, offered numeric estimates of jobs their projects would create in California. These estimates sum to 4,593 jobs, which equates to an average rate of one job created per $2,300 of PIER funding spent and $8,357 in match funding leveraged. If all 55 projects with the potential for job creation in California created jobs at this rate, about 29,580 total jobs would be created. When considering the entire amount of PIER funding committed to the PIER 2013 research portfolio, the creation of 29,580 direct jobs equates to one job per $6,300 of PIER funds.

For comparison, the Congressional Budget Office (CBO) scored the American Recovery and Reinvestment Act (ARRA) at a cost to the federal government of $831 billion over the years 2009-2019. The CBO estimated that ARRA resulted in the creation of 2.8 million full-time-

equivalent jobs (including indirect and induced jobs) at the peak of its impact on the U.S. economy in 2010, after which the effect on employment began to diminish.[62] This equates to one temporary, full-time job per $293,200 spent. Based on the multiplier effects used by the CBO for spending on renewable energy and energy efficiency,[63] the 29,580 direct jobs potentially created by successful PIER projects would result in an additional 14,790 indirect and induced jobs, bringing down the cost to $4,200 per total job created. Even if only the reported estimates of PIER-funded job creation were achieved, PIER's cost per job would come in around $27,040, substantially lower than ARRA.

62 Congressional Budget Office. 2012. *Estimated Impact of the American Recovery and Reinvestment Act on Employment and Economic Output from October 2011 Through December 2011.* http://www.cbo.gov/sites/default/files/cbofiles/attachments/02-22-ARRA.pdf

CBO provides two estimates of job creation, a low and high value. The discussion here refers to the middle of this range.

63 Ibid. See Table 2 for estimates of the multiplier effect associated with Division A, Title IV, of the law relating to energy. The estimates range from 0.5 to 2.5; the middle of this range is (1.5) is chosen for the purposes of this discussion.

CHAPTER 4: Conclusion

The rational pursuit of creativity and innovation in California's energy landscape has yielded and will continue to provide enormous returns on the investments made. The PIER Program has proven its ability to leverage its own investment funds to bring in private and federal dollars and create jobs while helping California build toward its planned energy future. The innovations funded by PIER save California electricity ratepayers millions of dollars every year, through improved system reliability, higher energy efficiency standards and codes, and the use of PIER-developed technologies and tools. Californians have benefited from products brought to the marketplace to reduce energy demand and costs, enhance generation performance, increase comfort and public safety, reduce environmental waste streams, and promote clean air. The projects highlighted in this report, as well as many others, have directly addressed barriers facing policy goals, sometimes even transforming and advancing the policies themselves, as in the case of PIER energy efficiency research.

As a significant influence on the world's economic and energy future, California has taken the leadership role of supporting aggressive policy goals and funding innovative energy projects that result in emerging technologies, standards, and strategies. The Energy Commission has invested more than $738 million for energy research and development through the PIER Electric program and leveraged its investment to attract more than $1.3 billion in match funding, reaping benefits that far outweigh the costs. Nobel laureate Robert Solow estimated that more than 90 percent of economic growth comes from investments in innovation. The private rate of return on RD&D is around 20 to 30 percent, while the social rate of return is around 66 percent.[64]

Over the last 16 years, the PIER Program responded to evolving policy goals and market needs. The program initially focused on research involving individual components and progressed to emphasize integration of multiple energy technologies to solve complex, interrelated issues and to maximize synergies and benefits. The program also enhanced its capabilities and processes in regards to collection and reporting of benefits data.

PIER has been one of the premier energy research programs in the country since 1996 and one of only several state programs of its kind in the nation. PIER research has been vital in the transformation of the state's energy policy landscape, providing clear and quantifiable results that policy makers and innovators have used to plan for the future. Although the PIER Electricity Research Program is not authorized to fund new future projects, its investments laid a foundation for continued progress toward California's clean energy future. The complexities and challenges of transforming the energy system that powers California are enormous; they must continue to be matched by capable, strategic, and comprehensive investment in innovation.

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64 Nemet, Gregory F. "Policy and Innovation in Low-Carbon Energy Technologies." Ph.D. dissertation, May 2007. https://mywebspace.wisc.edu/nemet/web/Thesis.html.

ACROYNMS

ARRA	American Recovery and Reinvestment Act
BIOS	Basic Input/Output System
California ISO	California Independent System Operator
CBO	Congressional Budget Office
CSI	California Solar Initiative
CPUC	California Public Utilities Commission
DG	distributed generation
EISG	Energy Innovations Small Grant
EPIC	Electric Program Investment Charge
GHG	greenhouse gas
GWh	gigawatt hour(s)
HVAC	heating, ventilation, and air conditioning
IAW	industrial, agriculture, and water
IEPR	*Integrated Energy Policy Report*
kW	kilowatt(s)
kWh	kilowatt hour(s)
MW	megawatt(s)
MWh	megawatt hour(s)
NO_x	nitrogen oxides
PC	personal computer
PCGA	PC Gaming Alliance
PEV	plug-in electric vehicle
PG&E	Pacific Gas and Electric
PGC	Public Goods Charge
PH&EV	Plug-In Hybrid & Electric Vehicle Research Center
PIER	Public Interest Energy Research
PM	particulate matter
PV	photovoltaic
RD&D	research, development, and demonstration
RPS	Renewables Portfolio Standard
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SMUD	Sacramento Municipal Utility District
SONGS	San Onofre Nuclear Generating Station
SO_x	sulfur oxides
SSD	solid-state drive
VR	ventilation rates
ZNE	zero-net-energy

APPENDIX A:
List of Projects Funded in 2013

This table summarizes new electricity research projects initiated (that is, agreements approved at an Energy Commission Business Meeting) during calendar year 2013. A total of 26 electricity projects were initiated in calendar year 2013.

Agreement Number	Entity	Project Title	Total Agreement Amount	Match Amount	Start Date*
PIR-11-017	Burbank Water and Power	Smart Grid High Concentration Solar Photovoltaic Integration	$1,000,000	$39,735,991	11/22/2013
PIR-11-031	Maxwell Technologies	Economic Benefits of Firm Concentrated Photovoltaic Energy for the Grid	$1,392,464	$434,000	8/2/2013
PIR-12-001	Pacific Gas and Electric Company	Advanced Underground Compressed Air Energy Storage Demonstration Project Using a Saline Porous Rock Formation as the Storage Reservoir	$1,000,000	$49,000,000	8/2/2013
PIR-12-003	Sierra Institute for Community and Environment	Plumas Energy Efficiency and Renewable Management Action Plan	$300,000	$150,000	6/19/2013
PIR-12-004	Foresight Renewable Solutions	Integrated Solar Photovoltaic, Advanced Compressed Air Energy Storage, and Microgrid Demonstration Project	$1,749,000	$1,243,570	6/19/2013
PIR-12-005	Electricore, Inc.	The Market Impact of Standardized Design in Plug-In Electric Vehicle Battery Pack Purchase and Disposal	$750,000	$150,000	6/19/2013
PIR-12-006	Farasis Energy, Inc.	Direct Recycling Technology for California's Plug-In Electric Vehicle Lithium-Ion Battery Packs	$749,710	$149,943	6/19/2013
PIR-12-010	City and County of San Francisco, Department of the Environment	Energizing Our Future: Community Integrated Renewable Energy Assessment	$300,000	$300,000	6/24/2013
PIR-12-011	City of Davis	Davis Future Renewable Energy and Efficiency	$300,000	$75,000	6/1/2013
PIR-12-012	Cogenra Solar, Inc	MaxSun: A Novel Community-Scale Renewable Solar Power System for California	$525,000	$155,659	6/14/2013

Agreement Number	Entity	Project Title	Total Agreement Amount	Match Amount	Start Date*
PIR-12-016	Cool Earth Solar, Inc.	Predictable Solar Power and Smart Building Management for California Communities	$1,726,438	$1,025,822	6/19/2013
PIR-12-018	South Tahoe Public Utility District	Renewable Energy Regional Exploration Project	$139,830	$72,352	6/8/2013
PIR-12-019	Sun Synchrony	Breakthrough Power Density for Rooftop Photovoltaic Applications	$475,095	$325,692	6/7/2013
PIR-12-022	Redwood Coast Energy Authority	Repowering Humboldt With Community-Scale Renewable Energy	$1,750,000	$1,793,762	6/19/2013
PIR-12-024	View, Inc.	Zero Next Energy Demonstration: Integration of Dynamic Daylighting and Passive Cooling/Heating for High Return on Investment	$1,542,233	$1,553,326	6/28/2013
PIR-12-025	Electric Power Research Institute	Demonstrating Scalable, Very Energy-Efficient Retrofits for Low-Income, Multifamily Housing	$1,351,283	$1,112,800	6/30/2013
PIR-12-026	Regents of the University of California on behalf of the California Institute for Energy and Environment	Innovative Low-Energy Occupant-Responsive Controls for Heating, Ventilation, and Air-Conditioning Systems	$1,629,399	$192,500	6/30/2013
PIR-12-027	The Regents of the University of California, Davis	Codes and Standards Quality Demonstration Program: Documenting Performance, Energy Savings, and Cost Characteristics for Energy-Efficient Technologies	$1,167,103	$121,600	7/12/2013
PIR-12-028	The Levy Partnership, Inc.	Advanced Envelope Systems for Factory-Built Homes	$1,433,568	$299,781	6/30/2013
PIR-12-031	Lawrence Berkeley National Laboratory	Small- and Medium-Building Efficiency Toolkit and Community Demonstration Program	$2,000,000	$254,790	6/30/2013
PIR-12-032	The Regents of the University of California, Los Angeles	Tools and Materials for Zero-Net-Energy California Buildings	$1,335,074	$0	6/30/2013
PIR-12-033	Harper Construction Company, Inc	Camp Pendelton Area 52 FractalGrid Demonstration Project	$1,722,890	$1,172,428	6/30/2013

Agreement Number	Entity	Project Title	Total Agreement Amount	Match Amount	Start Date*
500-12-001	The Regents of the University of California on behalf of the Scripps Institution of Oceanography	Investigation of Discrepancies in Regional Climate Projections for California: Detemining the Impact of Climate on Energy	$300,000	$0	2/18/2013
500-12-005	Humboldt State University Foundation	Aerial Line Transect Surveys for Golden Eagles Within the Desert Renewable Energy Conservation Plan Area	$200,000	$0	6/14/2013
500-12-007	U.S. Geological Survey	Research to Improve Golden Eagle Management in the Desert Renewable Energy Conservation Plan Area	$314,000	$14,700	6/21/2013
500-12-011	The Regents of the University of California on behalf of the California Institute for Energy and Environment	WESTCARB Phase III Support IAA	$751,928	$0	6/30/2013

*Start Date is the date the agreement was signed and executed.

APPENDIX B:
Benefits Methodology

The estimates for energy savings resulting from efficiency-related projects presented in Tables 4, 5, 7, and 8 of Chapter 3 were calculated as follows:

1. The Energy Commission collected data on benefits measured or expected from demonstration projects and benefits resulting from future technology transfer efforts. Data sources included final project reports, project proposals, direct communication with award recipients, or third-party sources. The data were limited to electricity savings, natural gas savings, and peak electrical load reduction. Where available or necessary, the data were provided as ranges. Ranges were necessary in some cases for projections to 2020, as market conditions remain to be seen. Many projects were omitted from this process because the stage of research was too early to provide sound data needed for an estimate of benefits.

2. The Energy Commission combined the data provided with the latest Energy Commission demand forecast for the relevant energy end-use sector (for example, residential, commercial, industrial).[65] In the case of projects related to data centers, a separate projection of electricity demand in 2020 was developed in expectation that data center electricity demand would grow substantially faster than the commercial or industrial sectors. The resulting forecast growth was based on projections prepared for the U.S. Energy Information Administration.[66]

3. Where estimates of future market uptake were not available, the potential benefits were evaluated at a conservative one percent realization of technical potential. Technical potential is defined as the benefits that would occur in California if the entire sector, ratepayer class, or other relevant market grouping adopted the technology. A factor of 1 percent is applied to the technical potential to provide conservative estimate of the benefits from actual market uptake. In a few cases, however, provided data justified the forecast of a greater level of market penetration. These are noted in the table of potential savings.

4. Emissions factors for electricity and natural gas were applied to the estimates of energy savings. The sources and assumptions for these emissions factors are discussed below.

5. Monetary savings were estimated as the product of forecast average energy rates in 2020 and energy savings, per the rate forecasts in the 2014-2024 Energy Commission demand forecast. Additionally, the value of GHG emission reductions was calculated at $11.5 per metric ton (the

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65 Alcorn, Bryan et al. 2013. *California Energy Demand 2014–2024 Final Forecast.* California Energy Commission, Electricity Supply Analysis Division. CEC-200-2013-004. http://www.energy.ca.gov/2013publications/CEC-200-2013-004/CEC-200-2013-004-SD-V1.pdf.

66 Navigant Consulting and SAIC. 2013. *Analysis and Representation of Miscellaneous Electric Loads in NEMS.* Prepared for U.S. EIA. http://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf

November 2013 market clearing price), and $118 per kW of peak load reduction (as an estimate of the capacity value of peaker generation).

6. For most projects, only point estimates of benefits were available. For other projects, ranges of possible values were provided. To provide estimates of central tendency as well as a range of high and low values for entire set of evaluated projects, staff applied statistical theory. The procedures are as follows:

- Point estimates were turned into bell-shaped normal probability distributions, centered at the estimate. For demonstration projects, 95 percent of the probability mass was within 10 percent of the estimate, meaning the estimate as interpreted as being within 10 percent of the correct value, with 95 percent confidence. For projections to 2020, the variance was widened by setting a standard deviation of a third of the value. This treats the estimate as having more than two thirds probability of being within one third of what the market will ultimately determine.
- Ranges were turned into uniform distributions, meaning the same likelihood was assigned to any number in the range.
- Sometimes lower bounds were given without upper bounds (for example, "energy savings are at least *x*"). These were turned into the right half of a normal distribution peaking at the lower bound and tapering to higher numbers with a standard deviation of one-third of the lower bound.
- Where low, high, and medium estimates were all provided, the most weight was put on the medium estimate. This was accomplished by creating a skewed normal curve, with its peak at the medium estimate and 95 percent of the values between the lower and higher estimates.
- The method used for combining probability distributions was repeated random simulations. In each simulation, a draw from each project's probability distribution was made, and the different projects were added together. Collectively, the simulations specified a distribution for the final outcome, total carbon or dollar savings. This approach is common in statistics.
- Once each project's estimate of carbon or dollar savings was converted into a probability distribution, the distributions were combined to create a final distribution. The mean of that distribution was reported as the total, and for potential savings the 25th and 75th percentiles were reported as the low and high values in parentheses. These can be considered low and savings high scenarios.

7. The results refer only to benefits. Cost data were not available. The evaluated projects were anticipated to deliver benefits greater than costs to ratepayers because of their substantial technical successes. However, realized costs will depend on a variety of factors that occur during commercialization, such as economies of scale achieved the financing costs faced by the firm delivering the new technology to ratepayers. Further, the benefits evaluated are limited

only to electricity savings, natural gas savings, and peak demand reduction. Benefits such as water savings or the avoidance of waste disposal were not evaluated.

In-Depth Analysis: Aerosolized Sealants

The Energy Commission generated an estimate of the net ratepayer benefits of 500-08-042, Project 3, *Aerosolized Sealant for Building Envelopes*. The contractor reported a 50 percent reduction in air leakage from the building envelopes of the demonstration homes. As air leakage accounts for about 30 percent of total HVAC energy use, the analysis assumes that a 50 percent reduction in air leakage would result in a 15 percent in total HVAC energy use in the residential and commercial sectors. Peak demand reductions were not analyzed for lack of data available from the contractor.

The material used in this project is similar to a currently commercialized product developed by the contractor for use specifically in sealing air ducts. The company that sells this product, Aeroseal, provides a 10-year warranty for residential treatment.[67] From this, it was assumed that the duration of the energy-saving effect of the aerosol treatment was at least 10 years.

As a plausible scenario of market penetration, it was assumed that the aerosol treatment for building envelopes would enter the market in 2016 and be applied to 1 percent of existing residential and commercial square footage, both new and existing, in that year. An additional 1 percent of the market is assumed to receive the treatment for each following year until 2024, inclusive. The year 2024 is the final year of the Energy Commission's latest forecast of energy demand.[68]

Projections of electricity and natural gas rates are also taken from this source. Separate rates are used for the residential and commercial sectors. Because the forecast provides only average, and not marginal rates, it is certain that the result will be an underestimate of the utility bill savings reaped by ratepayers. Ratepayers in higher rate tiers are more likely to adopt this product and will reap greater utility bill savings than the average ratepayer in lower rate tiers.

HVAC-related electricity consumption was estimated at 12.35 percent of total residential electricity consumption and 29.22 percent of total commercial electricity consumption.[69] These percentages were applied to each year of the electricity demand forecasts for each sector. HVAC-related natural gas consumption was estimated at 44 percent of residential natural gas consumption[70] and 57.4 percent of commercial natural gas use.[71] These percentages were applied to each year of the total natural gas demand forecasts for each sector.

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67 http://www.aeroseal.com/problem-we-solve/warranty.html

68 Alcorn, Bryan et al. 2013. *California Energy Demand 2014–2024 Final Forecast.* California Energy Commission, Electricity Supply Analysis Division. CEC-200-2013-004. http://www.energy.ca.gov/2013publications/CEC-200-2013-004/CEC-200-2013-004-SD-V1.pdf.

69 Internal Energy Commission data.

70 http://energyalmanac.ca.gov/naturalgas/residential_use.html.

The cost of the treatment was estimated by the contractor at $215 for a 1,200-square-foot home. From this, it was assumed that the average cost per square foot would equate to roughly 17.9 cents; economies of scale associated with large homes or commercial buildings were not estimated for lack of available data. This is likely to bias the costs upward.

Projections of the total (new and existing) commercial building square footage in California over the study period 2016 to 2024 were available from the 2014-2024 Energy Commission demand forecast.[72] Projections of total (new and existing) residential building square footage in California were not available, but estimates of the residential housing stock (single and multifamily) were available for 2012 from the American Community Survey.[73] These were projected through the study period using projected housing starts provided to the Commission by Moody's Analytics. To estimate the square footage, single-family housing units in California were assumed to average 1,783 square feet, while multifamily units were assumed to average 1,378 square feet. These values were derived from population-weighted averages of the results for each major metropolitan area in California represented in the 2011 American Housing Survey (AHS).[74]

For each year from 2016 through 2024, inclusive, 1 percent of total residential and commercial square footage was assumed to undergo the aerosol treatment. For 2016, upfront costs were estimated at $39.6 million for the residential sector and $13.4 million for the commercial sector (in 2013 dollars). Annual upfront costs incurred by ratepayers grow slightly over the study period as the total building stock grows. To account for the time-value of money, all costs and benefits are adjusted by the following discount factors:

Discount rate for residential ratepayers: 4.43 percent. This reflects the opportunity cost of the upfront purchase of the aerosolized sealant treatment, which could otherwise be put toward paying down household debt. The value was chosen from the national average for 30-year, fixed rate mortgages as of January 1, 2014 according to the Federal Reserve Economic Data (FRED) database series MORTG. http://research.stlouisfed.org/fred2/graph/?id=MORTG

Discount rate for commercial ratepayers: 3.62 percent. This reflects the opportunity cost of the upfront purchase of the aerosolized sealant treatment, which might require taking on extra debt

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71 Itron. 2006. *California Commercial End-Use Survey*. http://www.energy.ca.gov/2006publications/CEC-400-2006-005/CEC-400-2006-005.PDF.

72 http://www.energy.ca.gov/2013_energypolicy/documents/2013-10-01_workshop/spreadsheets/Mid/ STATEWIDE_Mid.xls

73 Selected Housing Characteristics (DP04), 2012 American Community Survey 1-Year Estimates for California. http://factfinder2.census.gov/faces/nav/jsf/pages/searchresults.xhtml

74 "Rooms, Size, and Amenities – All Housing Units (selected metropolitan areas), 2011 American Housing
Survey. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=AHS_2011_C02AHM&prodType=table

or otherwise deferring the paying down of debt. The value was chosen from the latest Federal Reserve Survey of Terms of Business Lending, conducted in November 2013;[75] the value refers to the weighted average effective loan rate for all commercial and industrial loans of duration greater than 365 days.

The analysis does not evaluate the monetary value of GHG emission reduction.

Environmental Impact of Avoided Electric Generation

The climate forcing and criteria pollutant emissions estimated in this report follow the methodology provided in the following source:

Alvarado, Al and Joe Loyer. 2012. *Criteria Air Emissions and Water Use Factors for Gas and Electricity Efficiency Savings for the 2013 California Building Energy Efficiency Standards.* California Energy Commission.[76]

The assumptions of this paper are updated here with the latest values to refine the analysis. These are noted in the discussion below.

The electric generation displaced by ratepayer energy savings is assumed to consist of a mix of natural gas and RPS eligible resources. For the year 2020 and beyond, the RPS requirements correspond to 33% of retail sales. For years prior, this percentage follows the compliance schedule provided on the CPUC's website.[77]

Additionally, avoided generation is assumed to consist of a mix of in-state and out-of-state resources. Per Alvarado and Loyer (2012), the marginal fraction of in-state fossil generation is set at 75 percent. Per the *Energy Aware Planning Guide*, the marginal fraction of in-state RPS generation is set at 80 percent.[78]

Ratepayer electricity savings must be "grossed-up" to account for transmission and distribution losses (T&D losses), which necessitate that more electricity be generated at power plants than is ultimately consumed by ratepayers. Alvarado and Loyer provide the following loss rates:

- In-State Generation: 7.8 percent
- Out-of-State Generation: 9.8%

Loss rates are used to calculate avoided net energy for load (total generation by power plants to serve retail electricity sales) as follows:

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75 http://www.federalreserve.gov/releases/e2/default.htm

76http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/General/2013_Initial_Study_Air_and_Water_Emission_Factors.pdf

77 http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/33RPSProcurementRules.htm

78 California Energy Commission. 2011. *Energy Aware Planning Guide*. Commission Report. CEC– 600–2009–013. Section II: Overview, Page 5.

$$Avoided\ Net\ Energy\ for\ Load = Avoided\ Retail\ Sales\ x\ \frac{1 - Loss\ Rate 1}{}$$

To estimate avoided GHG emissions, both in-state and out-of-state generation sources are considered. Non-CO_2 gases are ignored as they constitute a trivial fraction of the total global warming fraction of post-combustion natural gas.[79] A lifecycle analysis was not undertaken. The CO_2 emission rate for the marginal natural gas power plant is taken as 382 kg per MWh, which is estimated as the product of the average heat rate of combined-cycle natural gas plants in California in 2012 (7,228 btu/kWh)[80] and the carbon intensity of natural gas combustion per unit input (53.02 kg CO_2/mmBtu).[81] To enable sensitivity analysis, emissions factors associated with the range of heat rate rates provided in Alvarado and Loyer (2012) (7,000btu/kWh to 8,000 Btu/kWh) were retained.

For the GHG emissions of RPS resources, this analysis follows the assumption of the *Energy Aware Planning Guide* that one-third of new RPS resources will be geothermal, which is associated with small but measureable GHG emissions during operation (7.5 kg per MWh).[82] Emission factors are calculated for in-state natural gas, in-state RPS, out-of-state natural gas, and out-of-state RPS. Then, they are weighted by their relative share in the marginal power mix. For the year 2013, the result is 334.9 kg per MWh. For the year 2020, the result is 281.8 kg per MWh.

Reductions in ratepayer natural gas consumption are estimated to reduce GHG emissions in all years by a factor of 5.302 kg CO_2 per therm.[83]

Criteria pollutant emissions factors for natural gas-fired generation are taken from Table 3 of Alvarado and Loyer (2012). They are adjusted by the relative share of in-state, non-RPS resources in the marginal power mix. Reductions in criteria pollutant emissions outside the state are not considered, as reductions outside the state do not benefit California ratepayers.

Table 15: Criteria Pollutant Permit Emission Factors

NOX	0.07	lbs/MWh
SOX	0.01	lbs/MWh
CO	0.1	lbs/MWh
PM2.5	0.03	lbs/MWh

79 U.S. EPA. Emission Factors for Greenhouse Gas Inventories. http://www.epa.gov/climateleadership/documents/emission-factors.pdf.

80 Internal California Energy Commission data.

81 California Energy Commission. 2011. *Energy Aware Planning Guide*. Commission Report. CEC– 600–2009–013. Section II: Overview, Page 5.

82 Ibid.

83 California Air Resources Board. 2013. *Unofficial electronic version of the Regulation for the Mandatory Reporting of Greenhouse Gas Emissions*. Page 115. http://www.arb.ca.gov/cc/reporting/ghg-rep/regulation/mrr-2013-clean.pdf